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This program was an experimental effort to evaluate several methods of reducing the octane requirement of a 350 CID Chevrolet engine (1975 California model). Increased squish and two spark plugs per cylinder did not provide the expected gains in this particular application. Aluminum heads and a knock-actuated spark control system were identified as potential methods of reducing octane requirement.

The spark control system was incorporated into a vehicle emission control system to enable the use of higher compression ratio heads without substantial losses in emission control and with a gain in fuel economy.

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91 RON-INCREASED COMPRESSION RATIO ENGINE DEMONSTRATION

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ABSTRACT

A 1975 California model automobile with an 8:1 C.R. 350 CID engine was modified by increasing the compression ratio to 9:1 which resulted in improved fuel economy. The higher NO_x emissions were reduced to the base level by substituting a back pressure-controlled EGR unit for the original valve and increasing the EGR flow. Four approaches were tried in an engine dynamometer installation to lower the octane requirement of the 9:1 C.R. engine. These were (1) increase turbulence by increasing the squish area, (2) use dual spark plug ignition to minimize flame travel time, (3) use aluminum heads to obtain better heat transfer, and (4) use knock sensor-actuated spark retard to temporarily de-tune the engine when knock occurs. Of these, the latter approach showed the most promise and was installed in the vehicle to control the level of detonation in the modified 9:1 C.R. vehicle.

The knock sensor (accelerometer) is attached to one of the cylinder heads of the engine. When knock occurs, the vibration is picked up by the sensor, the signal is filtered to remove some of the engine background noise, and the knock pulse is detected. When the amplitude of the detected knock signal exceeds a threshold value, the spark timing is retarded. When no knocking is detected over a waiting period, the timing is advanced back to its normal schedule. Using this system, the vehicle's octane requirement can be lowered several numbers with some performance debit, i.e., slower acceleration times.

SECTION 1

INTRODUCTION

The objective of this work was to develop an increased compression ratio engine which could be operated on 91 RON unleaded fuel. At the higher compression ratio, the vehicle would achieve better fuel economy but also would produce higher NO_x emissions. Recalibration of emissions levels to the lower C.R. base case can be done using conventional means (e.g. increased EGR flow, etc.). However, the reduction of vehicle octane requirement to allow operation at the higher compression ratio necessitated a considerable effort to find a suitable approach. This subject, then, was the focus of attention during the research.

1.1 FACTORS AFFECTING OCTANE REQUIREMENTS

When an engine is operated on fuel of insufficient octane, detonation, or knock, occurs. Taylor and Taylor(1) present the following description of detonation:

> "It is now generally accepted that detonation is due to the autoignition of the end gas, which is the part of the charge which has not yet been consumed in the normal flame-front reaction. When detonation occurs, it is because piston motion, plus compression of the end gas by expansion of the burned part of the charge, raises its temperature and pressure to the point where the end gas **autoignites**. If the reaction of autoignition is sufficiently rapid, and a sufficient amount of end gas is involved, detonation can be observed."

The usual way of detecting detonation is by the audible "ping" it produces, though it is possible to record the pressure rise it creates, record the arrival of the flame front at a given point in the cylinder, or use a variety of other instrumental approaches.

Knock is a discrete event, which is dependent on events occurring in the individual cylinder. Two nominally identical engines may not knock under similar operating conditions, nor is it likely that all cylinders in a given engine will start to knock at the same threshold value. Any approach to the question of what conditions cause knock to occur must be statistical in nature.

Knock is objectionable for several important reasons. First, the noise of knock itself is objectionable. Second, knock may lead to localized overheating which in turn leads to preignition, that is, ignition before the spark plug is supposed to fire. Preignition causes loss of power and fuel economy, poor driveability, and may damage the engine. Finally, even without preignition, severe and prolonged knock can damage piston heads, exhaust valves, and piston rings.

There are two basic approaches to avoiding knock. First, is to design the engine in such a way as to keep the end gas temperature below the severe autoignition temperature or keep combustion time short enough to avoid detonation. This involves such steps as limiting compression ratio, adjusting spark timing, and designing combustion chambers to avoid large collections of end gas. Second, is to provide fuel which is less subject to autoignition. This can be done by controlling the hydrocarbon species in the fuel - isoparaffins and aromatics are less subject to autoignition than normal paraffins or olefins - or by use of additives such as tetraalkyl lead, which inhibit autoignition. Typically, the autoignition tendencies of fuels are characterized by octane number, determined either by the Research or Motor methods. Fuels are rated in comparison to mixtures of normal heptane, a straight chain paraffin with high autoignition tendencies, which is assigned zero octane number, and isooctane, a branched paraffin with low autoignition tendency, which is assigned an octane number of 100. Octane numbers of greater than 100 are compared against isooctane and given amounts of tetraethyl lead.

A second fuel related factor influencing tendency to knock is deposit forming tendency. All fuels form carbonaceous deposits in the combustion chamber. Fuels and lubes with lead or other metallic additives also form inorganic deposits. Deposits change the heat transfer characterisitcs of the combustion chamber. They tend to insulate the chamber and, therefore, increase the tendency for autoignition. Combustion chamber deposits build slowly to an equilibrium level during which time octane requirement increases. The amount of octane requirement increase observed depends on the characteristics of the fuel, the mileage accumulation schedule, and the characteristics of the engine used. This subject will be discussed in greater detail below.

As mentioned above, knock is a discrete phenomenon and can only be treated statistically. In the following sections, the effects of individual engine parameters on tendency to knock will be discussed. The differences between clean and equilibrated engines, and a statistical survey of octane requirements will also be illustrated.

COMPRESSION RATIO - Compression ratio is one of the primary determinents of octane requirement. Figure 1-1 shows the research octane number required to satisfy 90% of the vehicle population on full boiling range unleaded fuels as a function of compression ratio. These data were estimated by Corner and Cunningham(2) from data obtained in the CRC Octane Number Requirement Survey. These historical data indicate that 91 RON fuel will satisfy 90% of the vehicles at ~7.5:1 compression ratio. Since average compression ratio for the 1975 model year is assumed to be ~8.2:1, a significant portion of the vehicles on the road will not be satisfied unless some of the "mechanical octane" changes assumed possible in this proposal are used.

FIGURE 1-1

RESEARCH OCTANE REQUIREMENT FOR 90% CAR SATISFACTION ON UNLEADED FUEL (2)

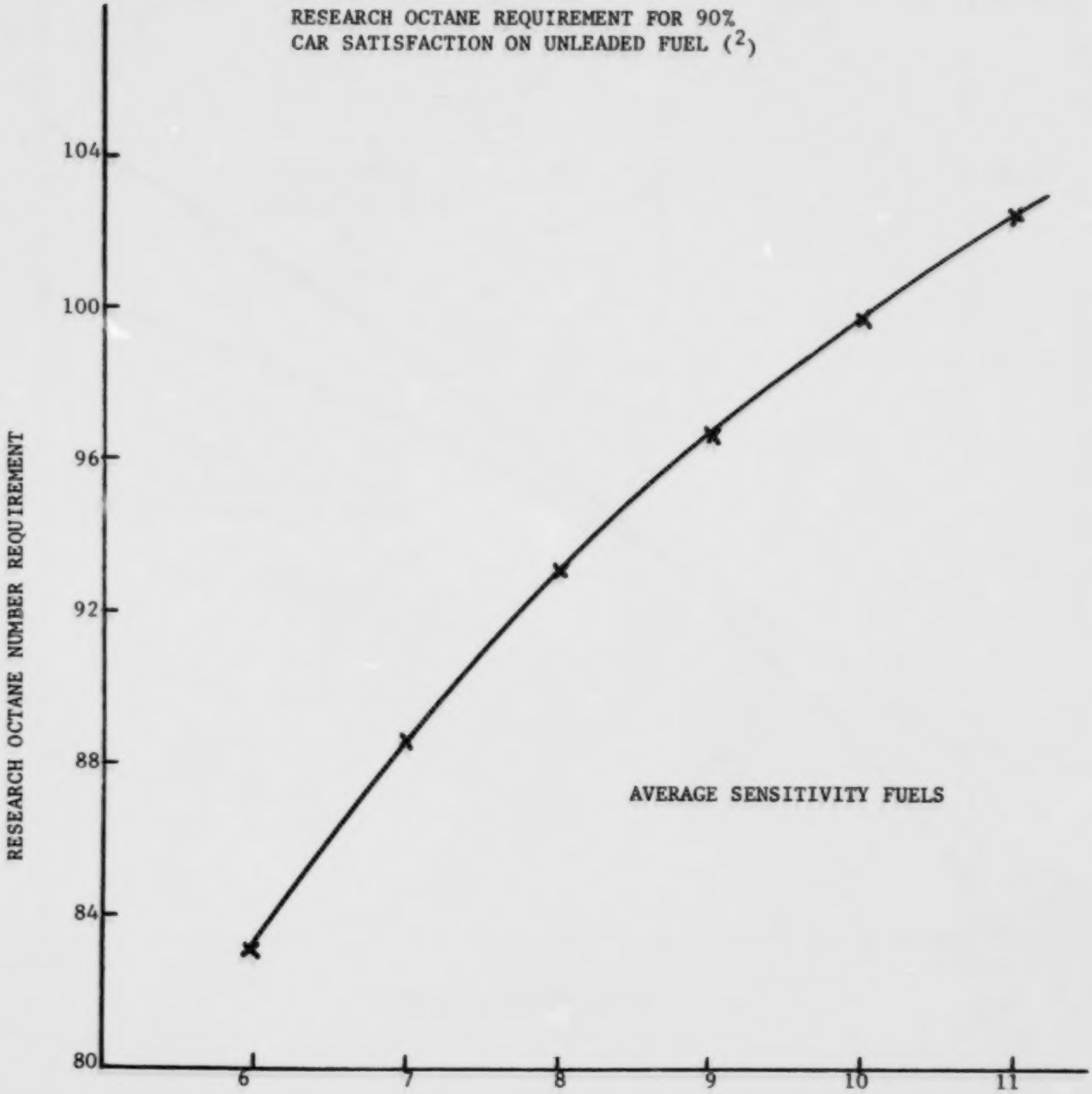
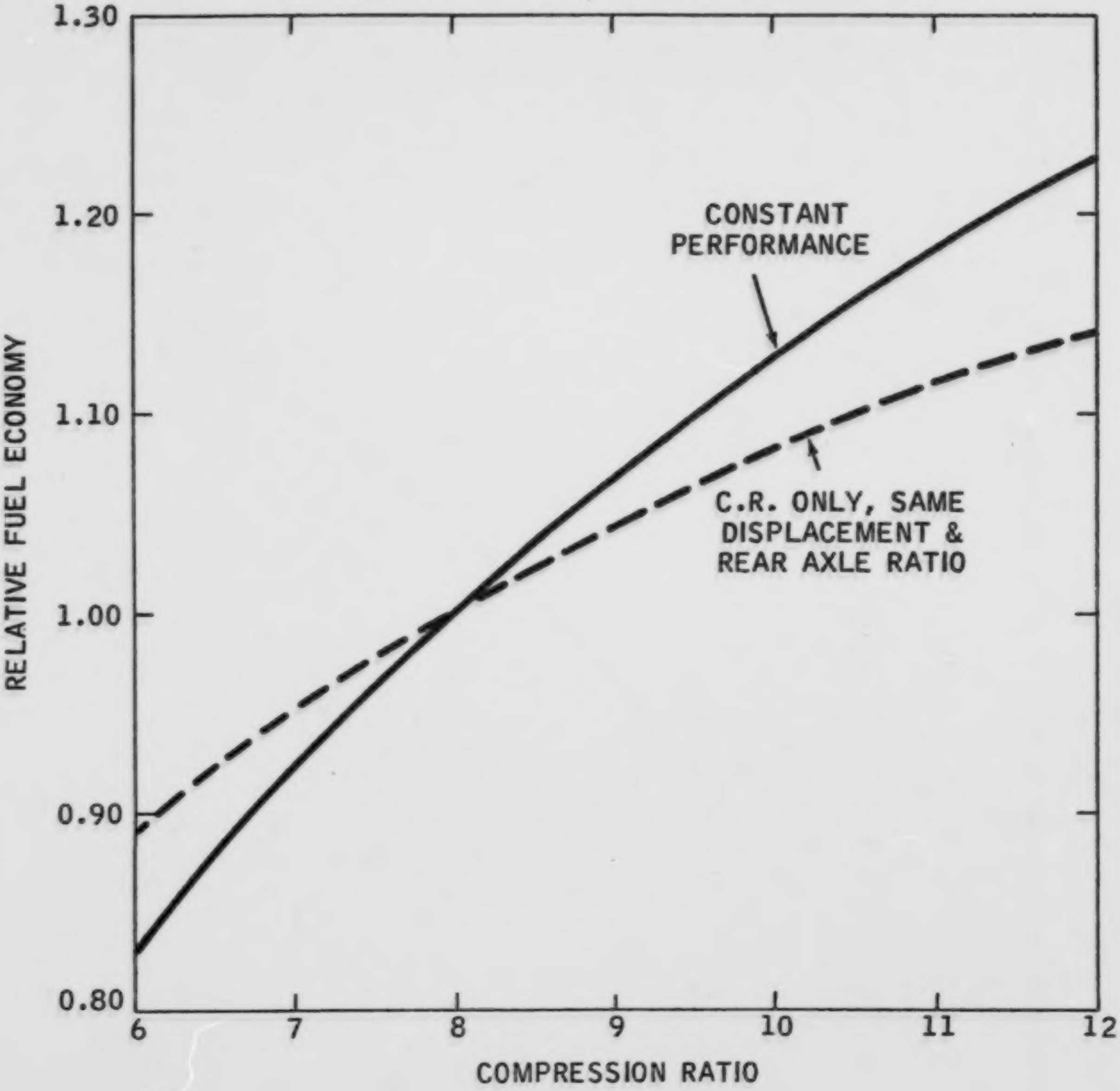


Figure 1-2

EFFECT OF COMPRESSION RATIO ON
RELATIVE FUEL ECONOMY

LEVEL ROAD, 40 MILES PER HOUR



Compression ratio also has a significant effect on fuel economy. Corner and Cunningham also present a survey of the literature in this area. Figure 1-2 shows the effect of compression ratio on fuel economy for two cases, one in which performance is held constant by changing engine size and/or rear axle ratio, the second in which compression ratio is changed without making other changes in the engine. These data are for level road, 40 mph cruise conditions and represent tests by a number of different investigators using a wide variety of engines.

In actual customer use, only part of the steady state fuel economy benefit will be realized. Corner and Cunningham estimated that 80% of the steady state benefit would be available and that the automotive industry would make the changes necessary to maintain constant performance. The resulting fuel economy benefit as a function of compression ratio is shown in Figure 1-3.

Compression ratio generally has a major effect on NO_x emissions with smaller effects on CO and HC emissions. As compression ratio is raised, peak cylinder temperature rises and NO_x formation rate increases. In one typical experiment conducted by Exxon Research, raising compression ratio from 9:1 to 11:1 at an air-fuel ratio of 14.4 lbs. air/lb. fuel, raised NO_x emissions 68%. An increase in compression ratio would have to be accompanied by steps to lower NO_x emissions back to acceptable levels.

The data in Figure 1-1 show that octane requirement increase is a non-linear function of compression ratio, but that over the range of compression ratios from 7 to 10, octane requirement increases about 3.5-4 numbers/compression ratio. The data in Figure 1-3 show about a 5% increase in fuel economy/compression ratios. Therefore, compression ratio changes result in 1.3% improvement in fuel economy/octane number requirement increase.

SPARK TIMING - In order to maximize the work obtained from an Otto cycle engine, the pressure-volume integral for the expansion stroke must be maximized. This is achieved if peak pressure is reached slightly after the piston reaches its top dead center (TDC) position. The fuel-air mixture must be ignited before TDC to obtain this condition, that is, spark should occur in advance of TDC. Spark timing is usually stated in terms of crank angle degrees before or after TDC. The more degrees before TDC the spark occurs the more spark advance. Delaying spark, even if spark still occurs before TDC, is referred to as spark retard.

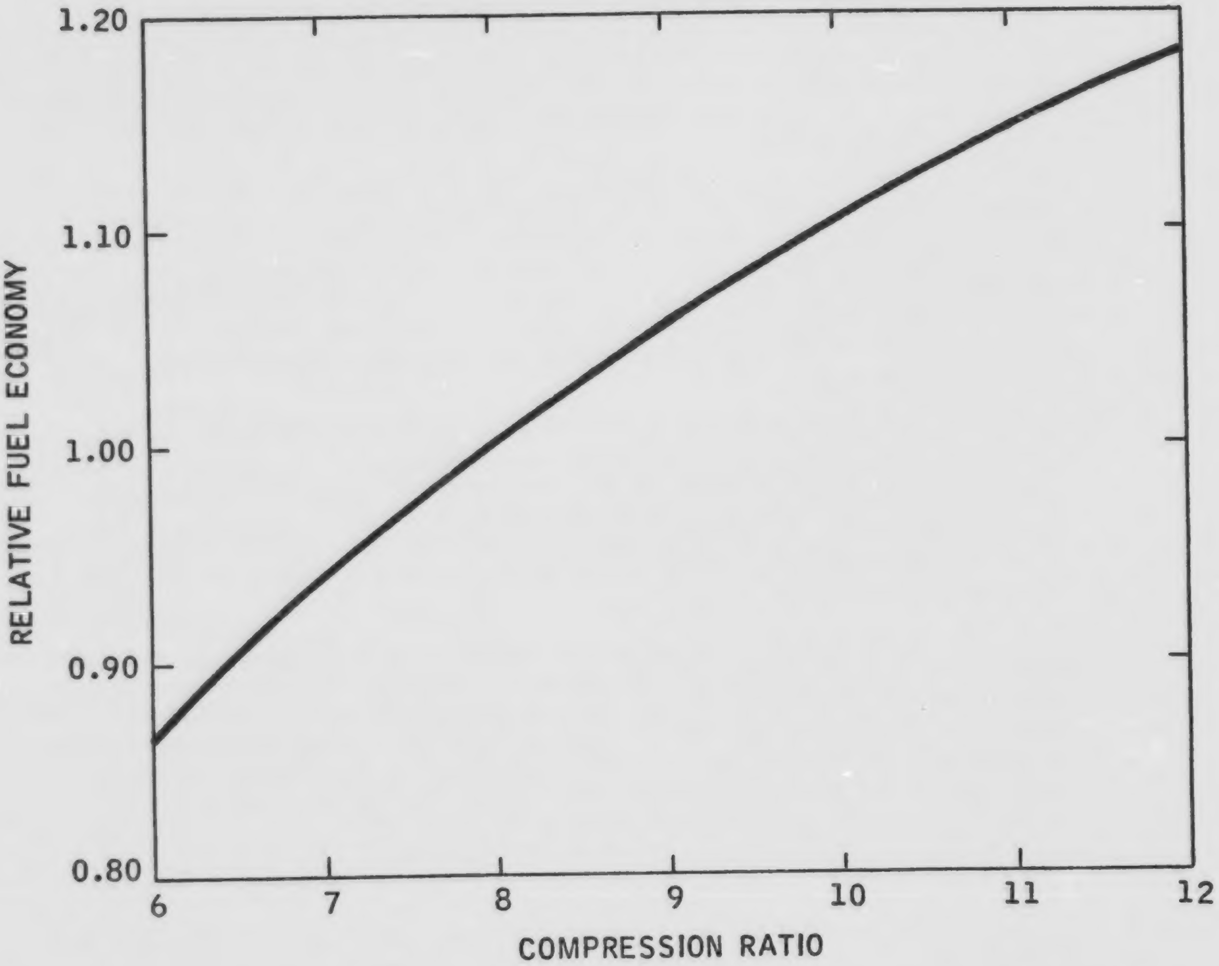
The optimum amount of spark advance varies widely with operating conditions. To provide the proper amount of advance under a wide range of conditions, three types of control are used. The first of these is a basic timing adjustment. This is the amount of advance needed to obtain proper performance at low engine speeds. In most engines, basic timing is set between TDC and 12 degrees before TDC. This adjustment is made with vacuum advance (described below) disconnected.

The second control is vacuum advance. At lower power outputs, the engine operates at high intake manifold vacuum levels, and therefore, at low peak cylinder pressure. Lower pressure in the cylinder means

Figure 1-3

EFFECT OF COMPRESSION RATIO
ON CUSTOMER RELATIVE
FUEL ECONOMY

80% OF LEVEL ROAD, 40 MILES PER HOUR



reduced flame speed. To obtain peak pressure at the correct time in the cycle, spark must be advanced. Most engines use an intake manifold vacuum actuated control to advance spark automatically.

The third control is centrifugal advance. As engine speed increases, the time available for the air-fuel charge to burn decreases. To allow time for the flame to develop properly, it is necessary to advance spark as a function of engine speed. This control is known as centrifugal advance.

Spark timing has a significant effect on emissions, fuel economy, and octane requirement. Since optimum timing results in the maximum temperature and pressure in the cylinder, it will also result in peak NO_x formation. Retarding spark timing is one of the popular methods of reducing NO_x emissions. Retarding spark timing will also generally reduce HC emissions. With retarded timing, less of the fuel's chemical energy is converted to mechanical energy. More is rejected as sensible heat in the exhaust. Higher exhaust temperatures promote post engine oxidation of hydrocarbons, and therefore, lower HC emissions. The effect of spark retard on CO emissions is relatively small and mixed. In some cases spark retard causes small reductions in emissions; in others, small increases.

Spark retard increases fuel consumption. Since with spark retard, less of the fuel's chemical energy is converted to work, more fuel must be consumed to do a given amount of work. Teasel, Calcamuggio, and Miller(3) showed a fuel economy debit of 1% per degree of spark retard.

Spark retard also reduces octane requirement. Since peak cylinder temperature and pressure are reduced, the tendency to knock is reduced. In 1970, the CRC Octane Number Requirement Survey included a study of the effect of 5 degrees spark retard on octane requirements. The average reduction in requirement for the roughly 100 cars tested was 0.7 octane number per degree of spark retard(4). Putting the octane requirement data and the fuel economy data together yields a fuel economy penalty of 1.4%/octane number requirement decrease if spark retard is used to reduce octane requirement. It should be realized, however, that spark retard will also cause a performance debit. If the amount of spark retard used is small, 5° or less, the power debit at the peak of the power curve is fairly small. For example, Caris, et al.(5) showed a 5 RON reduction in requirement for a 1% loss in peak power with 5° spark retard. At less than peak power, spark retard will cause greater reductions in power. Spark timing curves are typically retarded at the low speed, high load conditions which create maximum potential for detonation. This allows use of higher compression ratio and better efficiency at other operating conditions.

EXHAUST GAS RECYCLE (EGR) - EGR is a means of controlling NO_x which involves taking part of the exhaust stream and recycling it to the intake manifold. This adds diluent to the combustion mixture and therefore, lowers combustion temperature which results in lower NO_x formation rates. EGR generally has smaller effects on HC and CO emissions.

Since EGR functions by lowering peak flame temperature, it should be expected to lower octane requirement. EGR does in fact lower octane requirement. Musser, et al.(6) showed a decrease in octane requirement of 0.5 octane number/% EGR used. EGR is not used at full throttle in production vehicles because it reduces fuel economy at full throttle. However, at the more usual part throttle operation, a greater throttle opening, hence increased intake manifold pressure, is required to maintain constant power when EGR is used. Higher intake manifold pressure means less pumping loss, hence improved engine efficiency. This can compensate, at least in part, for the fuel economy lost by lower peak flame temperatures induced by EGR. EGR also lowers flame speed. To combust the charge at the appropriate time then, it is necessary to advance spark timing. The optimum air-fuel ratio for fuel economy moves to richer values with EGR for the same reason. Rich mixtures burn with faster flame speeds. Gumbleton, et al.,(7) showed that by adjusting spark timing and air-fuel ratio, it is possible to operate with as much as 15% EGR with no loss in fuel economy or part throttle performance compared to an optimized non-EGR case.

At full throttle, the reduction in pumping loss obtainable by opening the throttle wider is no longer available. Significant losses in performance occur because of the lower peak flame temperature. Glass et al.(8) give the following data on this subject:

Table 1-1 Effect of EGR at Wide Open Throttle (WOT) on 0-60 mph Acceleration Time

	% EGR	0-60 WOT Accel. Time	% Over Base
318 CID Plymouth	0	11.76	---
	7	13.68	16.3
	9.5	14.22	20.9
	12.5	15.0	27.6
307 CID Chevrolet	0	16.6	---
	13.3	19.4	16.8
	20.2	26.3	58.4

The effect of EGR on WOT performance is great enough to make a fuel economy comparison between the non-EGR and EGR cases meaningless.

OTHER DILUENTS - Other diluents will have the same effect on peak flame temperature that EGR has. Therefore, they will also decrease knock but at the cost of reduced power. The diluent most often discussed in this context is water. Proponents of this approach point out that water injection was used in World War II piston engine aircraft to allow peak power to be developed at low altitude. The argument made is that water injection at WOT in an automobile engine would allow a reduction in octane requirement with no reduction in peak power or fuel economy. This argument overlooks the basic differences between a World War II aircraft engine and an automobile engine.

The aircraft engine was designed to provide a given power level at high altitude where ambient pressure is low. To provide reasonable charge density the engine was supercharged. If the supercharger were allowed to act at low altitude with no other compensation, very high peak cylinder temperatures would develop. The engine would either knock or develop excessive thermal loads. Engines and fuels which could tolerate these peak cylinder pressures could be developed, but these would have been overdesigned for high altitude. The more reasonable approach was to allow the engine to operate near design limit at high altitude and reduce peak "potential" power at low altitude. Water injection did this.

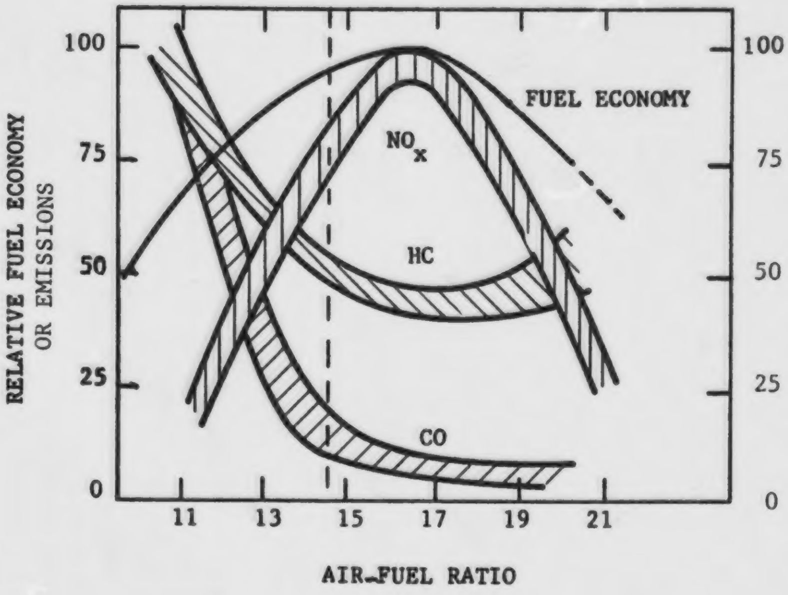
The automobile engine does not operate over this wide range of ambient conditions and therefore, does not need to be designed for reduced "potential" power. The cost of water injection is such that it could not compete with the means of suppressing knock already in the engine compartment.

AIR-FUEL RATIO - Air-fuel ratio affects octane requirement because it too affects peak cylinder temperature. Operating either with excess fuel (richer than stoichiometric) or excess air (leaner than stoichiometric) dilutes the burning charge and lowers peak cylinder temperature. Lower peak cylinder temperature results in lower octane requirement. As a rule of thumb, each air-fuel ratio leaner than stoichiometric lowers octane requirement 4 octane numbers.(5) The effects of air-fuel ratio on emissions and fuel economy are shown in Figure 1-4. Fuel economy is a non-linear function of air-fuel ratio. Therefore, it is difficult to calculate a fuel economy debit/octane number requirement decrease for changes in air-fuel ratio as had been done for changes in compression ratio, spark timing, and EGR rate. Such a computation would probably be of academic interest only, however. Most emission control systems depend on relatively tight control of air-fuel ratio and changing air-fuel ratio to change octane requirement would cause great difficulty.

COMBUSTION CHAMBER PROPERTIES - Since knock takes place in the end gas region, anything which changes either the degree of turbulence, in the chamber, the time for which the end gas exists, or the heat transfer characteristics of the region will affect the tendency to knock. Increasing turbulence should propagate the flame across the combustion chamber at a faster rate, leaving less time for autoignition to occur. Similar effects can be obtained by changing the shape of the combustion chamber or the location of the spark plug. Finally increasing

Figure 1-4

FUEL ECONOMY AND AIR-FUEL RATIO



heat transfer from the end gas zone cools the end gas and reduces the tendency to knock. Conversely, insulating the end gas zone with combustion chamber deposits will reduce heat transfer and increase the tendency to knock. Each of these subjects is discussed below.

Turbulence - The effects of increased turbulence on octane requirement have been studied by many investigators, but no method for accurately measuring changes in turbulence in the combustion chamber has been developed. One common approach to increasing turbulence is to shroud the intake valve. It involves masking a portion of the intake valve and thus forcing all of the intake charge to flow through a restricted portion of the normal intake opening. This causes the incoming charge to swirl as it enters the cylinder. A drawing of a shrouded intake valve is shown in Figure 1-5(a). Caris, et al.(5) present data of the effects of 90° and 180° shrouds in a single cylinder engine. At high engine RPM, the srouds caused a significant reduction in power since they acted as throttles. Power reductions occurred at engine speeds above 2000 RPM with the 180° shroud and above 2500 RPM with the 90° shroud. However, at lower speeds definite octane reductions were observed. At 1000 RPM, 9:1 compression ratio, the unshrouded engine required 98 RON. The 90° shroud reduced this to 95 RON; the 180° shroud to 93 RON. While these results are interesting, their practical application is severely limited by the throttling effect of shrouds.

Another, more practical approach to creating combustion chamber turbulence is to design the piston so that part of it matches the head at top dead center with only enough clearence to prevent interference. This has the effect of physically displacing the charge from one side of the chamber to another as the piston approaches top dead center. The thin zone thus created is generally referred to as a squish zone.

There are two general approaches to creating a squish zone. The first is to use a flat piston head and a wedge shaped cavity in the cylinder head. The second is to use a flat cylinder head and a bowl shaped cavity in the piston head. Both configurations are shown in Figure 2-5(b). Caris, et al.(5) show single cylinder engine octane requirement data comparing a flat cylinder head-flat piston head configuration with a flat cylinder head-bowl shaped cavity in the piston head configuration. At 1000 RPM, 9:1 compression ratio, the piston head with the cavity had a 19 RON lower requirement. No such direct comparison was made for wedge shaped combustion chambers.

Besides increasing turbulence, a squish zone increases heat transfer from the end gas and decreases its volume. Thickness of the squish zone is important in this respect. Caris, et al.(5) present octane requirement data for a single cylinder engine in which a depression in the piston head provided essentially all of the combustion chamber volume. Reducing the clearance between the cylinder head and the portion of the piston head not containing the depression from 0.100 inch to 0.040 inch reduced octane requirement by 10 numbers.

FIGURE 1-5

METHODS OF CREATING TURBULENCE IN COMBUSTION CHAMBERS

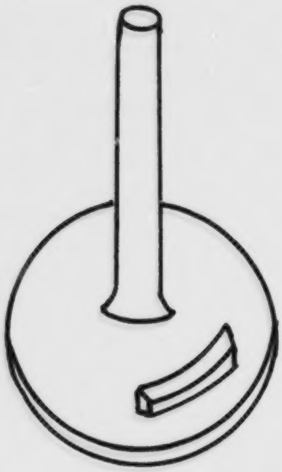
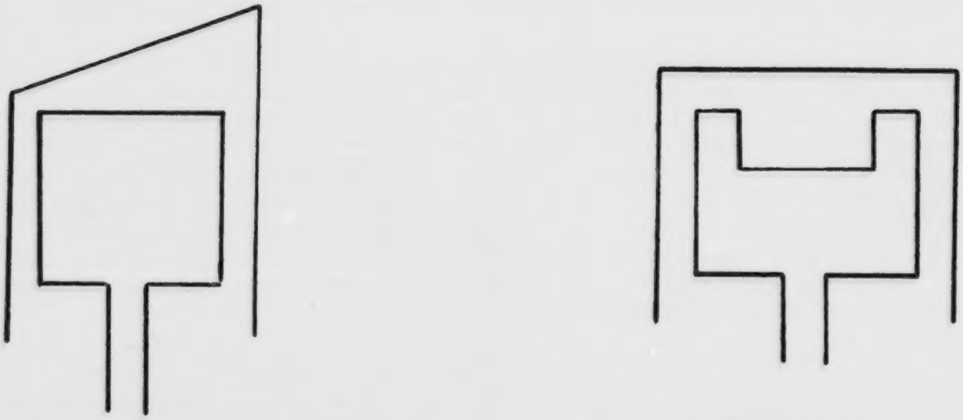


FIGURE 1-5 (a) SHROUDED INTAKE VALVE



WEDGE SHAPED
COMBUSTION CHAMBER

DEPRESSION IN
PISTON HEAD

FIGURE 1-5 (b) SQUISH ZONES

It should be remembered that Caris, et al. studied these problems in single cylinder engines with clean combustion chambers. Their results should be considered qualitative rather than quantitative. since, at best, only part of the benefit they observed would be found in a multi-cylinder engine operating with deposited combustion chambers. Despite this qualificiation, the benefits of squish zones were widely recognized, and by the mid-1960's they were a feature on most engines.

However, with the advent of emission control standards, squish zones had to be reevaluated in terms of their effect on emissions. The specific problem was the effect that squish zones have on hydrocarbon emissions. Most emitted hydrocarbon is the product of incomplete combustion, but part is fuel which survives the combustion chamber unburnt in a thin layer near the combustion chamber walls known as the quench zone. Quench zones exist because mechanical considerations dictate that the walls of the combustion chamber must be kept fairly cool. These cool walls quench the approaching flame a finite distance from themselves, thus creating the quench zone. All other factors being equal, the amount of hydrocarbon emitted from the quench zone is directly proportional to the surface-to-volume ratio of the combustion chamber. Combustion chambers with squish zones have higher surface-to-volume ratios than those without squish zones.

As a result, in the late 1960's when many auto manufacturers redesigned the combustion chamber of their engines to reduce surface-to volume ratio, they partially eliminated the squish zone and thus tended to increase octane requirement. Because these changes were made at the same time as major changes in air-fuel ratio and spark timing, it is impossible to quantify the magnitude of the effect of changes in combustion chamber design on octane requirement by comparison from one model year to the next.

Combustion Time Considerations - Knock is the result of chemical reactions occurring in the end gas region. These reactions are rate controlled and if insufficient time is allowed for the reaction to proceed, the flame will pass through the end gas region before knock occurs. The most critical factor in determining the time available for end gas reactions to occur is engine RPM. Knock may occur at the beginning of a wide open throttle acceleration, while engine speed is low, and disappear as engine speed increases. One method of minimizing the time required for the flame to travel through the combustion chamber is to place the spark plug in the center of the combustion chamber rather than at one end. This is done in most engines.

A further reduction in combustion time can be obtained by using multipoint ignition. This approach is attractive because it does not debit either power or fuel economy as do spark retard, use of EGR at full throttle, and the other techniques discussed above. In fact, directionally, multipoint ignition tends to increase efficiency and power by more closely approximating constant volume combustion.

Lichty(10) reports on the beneficial effect of using two spark plugs at opposite ends of the combustion chamber in valve-in-head engines. Taylor and Taylor(1) report on the effect of spark plug location on knocking tendency using as many as 17 spark plugs in a single cylinder engine. They show a substantial reduction in the octane requirement of the engine when all 17 plugs fired simultaneously. Of course, the authors themselves say that the practical approach would make use of two spark sources.

Varde and Lucas(11) reported that dual spark plug ignition shortens the combustion duration and thereby reaches higher maximum cylinder pressures at a higher rate of pressure rise. This would be expected to produce more power and greater NO_x emissions which was found to be the case. Studies at General Motors(12) agree with these findings. In addition, by diluting the intake charge with N_2, large reductions in the NO_x emissions were obtained primarily due to thermal effect.

The firing of the two sparks at different locations effectively acts as if the spark were advanced, as far as the pressure rise curve is concerned. Accordingly, the firing of the two plugs can be retarded to a point such that the peak pressure with two plugs is the same as obtained with one plug fired at the normal time. Again the benefits of reduced combustion time is obtained while retaining a more or less normal pressure rise. Without an undue increase in complexity, the two approaches could be combined, i.e., a delay between primary and secondary ignition with an overall retard of the primary ignition.

Combustion Chamber Deposits - Octane Requirement Differences Between Clean and Equilibrated Engines - It has been well established by numerous experiments that the octane requirement of engines increases from its value at zero miles to an equilibrium value. The magnitude of this octane requirement increase, or O.R.I., is dependent on the driving mode used during equilibration. The time required to reach equilibrium depends both on driving mode and fuel type.

O.R.I. is associated with the build-up of combustion chamber deposits. It is easy to picture these deposits filling part of the combustion chamber, raising the effective compression ratio, and thus raising octane requirement. This mechanism probably accounts for part of O.R.I., but the insulating effect of combustion chamber deposits seems to be more important. Insulating the combustion chamber raises end gas temperature and the tendency to knock. Combustion chamber deposits are composed of very high molecular weight carbonaceous materials, oxides of the metals present in lubes, and when leaded fuels are used, lead salts. All of these materials are good insulators.

Equilibrium occurs when the rate of combustion chamber deposit lay down is equalled by the rate of deposit scavenging due to thermal and mechanical shocking. Total O.R.I. to equilibrium depends on the driving mode used. O.R.I. will be high, up to ∿10 octane numbers, if a cycle with mild and/or infrequent accelerations is used, since this type of driving minimizes mechanical scavenging of deposits. Driving cycles with frequent and/or hard accelerations lead to lower O.R.I.'s because of better deposit scavenging.

In this context, the octane rating procedure with its repeated wide open throttle accelerations (See Section 2.2.1) is a good means of scavenging deposits. The act of octane rating an engine will reduce its octane requirement several numbers. Duplicate rating should always be made after some intervening mileage accumulation.

The time required to reach equilibrium depends on the fuel used. With leaded fuels at least 5,000 miles is normally considered sufficient time to reach equilibrium. However, with unleaded fuel, longer mileage accumulations are necessary. In our view, the reason for this is not understood at this time. In a 12 car program conducted by Exxon Research in 1971, we found that ∿7,500 miles was sufficient to reach equilibrium with unleaded fuel in simulated urban driving. A representative of General Motors(13) stated publically that equilibrium was reached within 12,000 miles of consumer driving on unleaded fuel. O.R.I. for this study was ∿7 numbers. Both values may be correct since the approach to equilibrium is a function of driving mode as well as fuel type.

OTHER ENGINE PARAMETERS - At least two other engine parameters have small but measurable effects on octane requirement. These are the temperature of the inlet air-fuel charge and the temperature of the coolant. Raising either temperature affects the heat balance in the cylinder and raises the end gas temperature, thus raising the tendency to knock.

AMBIENT CONDITIONS - Atmospheric temperature, pressure, and humidity all have an effect on end gas temperature. Raising either atmospheric temperature or pressure will raise end gas temperature and therefore tendency to knock. Moisture in the inlet air is a diluent which lowers end gas temperature. The effect of atmospheric pressure has been measured by the CRC in terms of the effect of altitude change on octane requirement of late model cars.(13) The average octane number requirement decrease for thirty-nine 1971 and 1972 model year cars was ∿2/in. of Hg pressure decrease.

RESEARCH OCTANE NUMBER VS. MOTOR OCTANE NUMBER - Thus far we have discussed octane requirement as if it were a single value and where data have been presented, they have been in terms of Research Octane Number Requirement. As stated earlier, there are two generally accepted methods of measuring octane number - the Research Method (ASTM Procedure D2699) and the Motor Method (ASTM D2700). Both methods use single cylinder, variable compression ratio engines and rate normal heptane as zero octane and isooctane as 100 octane. The Research Method is conducted at 600 RPM with an inlet air temperature of 125°F. Conditions for the Motor Method are somewhat more severe - 900 RPM and 300°F inlet air temperature.

Most fuels show a lower rating by the Motor Method than by the Research Method. The difference between the octane number determined by the two methods is referred to as "sensitivity." Sensitivity is a function of the chemical composition of the fuel. Paraffins and isoparaffins have relatively low sensitivity; aromatics and especially olefins, higher sensitivity.

Neither Research Octane nor Motor Octane Number exactly predict the octane requirement of vehicles in use. The CRC handles this problem by defining "road octane." The road octane number of a fuel is the octane number of a primary reference fuel, i.e,. a blend of isooctane and normal heptane, which has the same knocking characteristics as the fuel in question.

As a general trend, modern vehicles have become more dependent on Motor Octane Number. The importance of Motor Octane Number was recognized by the FTC, the auto industry and the petroleum industry in the decision to post octane number as an average of Research and Motor Octane Numbers, rather than posting just Research Octane Number as had typically been used in advertising. Reasons for the rising importance of Motor Octane Number are discussed below.

EFFECT OF TRANSMISSION CHARACTERISTICS ON MOTOR OCTANE NUMBER DEPENDENCE - A number of literature references (14-16) have discussed the knocking behavior of engines used with automatic transmissions. There is unanimous agreement in the literature that as engine speed increases, Motor Octane Number becomes a better predictor of fuel requirement than Research Octane Number. The use of automatic transmissions with torque convertors prevents engine loadings at speeds below the stall speed. Since the operating regime of engines with these transmissions is limited to a higher speed range, it should be expected that they respond to Motor rather than Research Octane Number. One method of relating the relative importance of Research and Motor octane is with a road octane number equation. Let:

$$\text{Road O.N.} = a\,(\text{RON}) + b\,(\text{MON}) + c, \qquad (2\text{-}1)$$

where: RON = Research Octane Number, and
MON = Motor Octane Number,

Then the relative importance of RON and MON is given by the ratio a/b. Fell and Hostetler(16) give this ratio as 15.7 for vehicles equipped with manual transmissions, but only 5.6 for vehicles equipped with automatic transmissions.

OCTANE REQUIREMENTS FOR ACTUAL VEHICLES - It should be obvious from the foregoing that estimating the equilibrated octane requirement of an engine from its design parameters is an impossible task. The large number of independent variables leads to a significant spread in the octane requirements of nominally similar vehicles. Figure 1-6 shows octane requirement data for 35 1973 V-8 vehicles of the same make and model obtained in the CRC's 1973 Octane Number Requirement Survey(17) using an 11 sensitivity fuel series. Minimum Octane Requirement was less than 84.5 RON, maximum greater than 100 RON. These type data are usually plotted as percent of cars satisfied by a given octane fuel. CRC plots such data for 12 models, each plot being based on 13-24 cars. The spread between the 10 and 90% satisfaction points for a given model for RON with full boiling range fuels averages about 10 numbers. For MON average spread is about 7 numbers. Spreads for the entire 1973 population (see Figures 1-7 and 1-8) are even larger.

The wide spread in the octane requirements of nominally similar vehicles presents serious problems in doing research on octane requirements. The only completely valid approach, the statistical approach in which measurements are made on a sufficient number of vehicles to characterize the population, is extremely costly and time consuming. Most research has been done in single engines with well characterized deposits where comparisons of the effects of different fuel and engine variables can be made. This is the approach used in determining octane number in single cylinder engines. The disadvantage to this approach is that results obtained in one engine may not be directly applicable to other engines. For example, a road octane equation must be developed to apply the octane number results obtained in single cylinder engines to multicylinder engines. The problem is particularly severe when a small number of engines is used. Neither the statistical approach nor the approach of well characterizing a particular engine can be used. Normal engine to engine variation can make interpretation of results extremely difficult.

FIGURE 1-6

DISTRIBUTION OF RESEARCH OCTANE NUMBER REQUIREMENTS
ON ~11 SENSITIVITY FUELS
35 - NOMINALLY SIMILAR VEHICLES

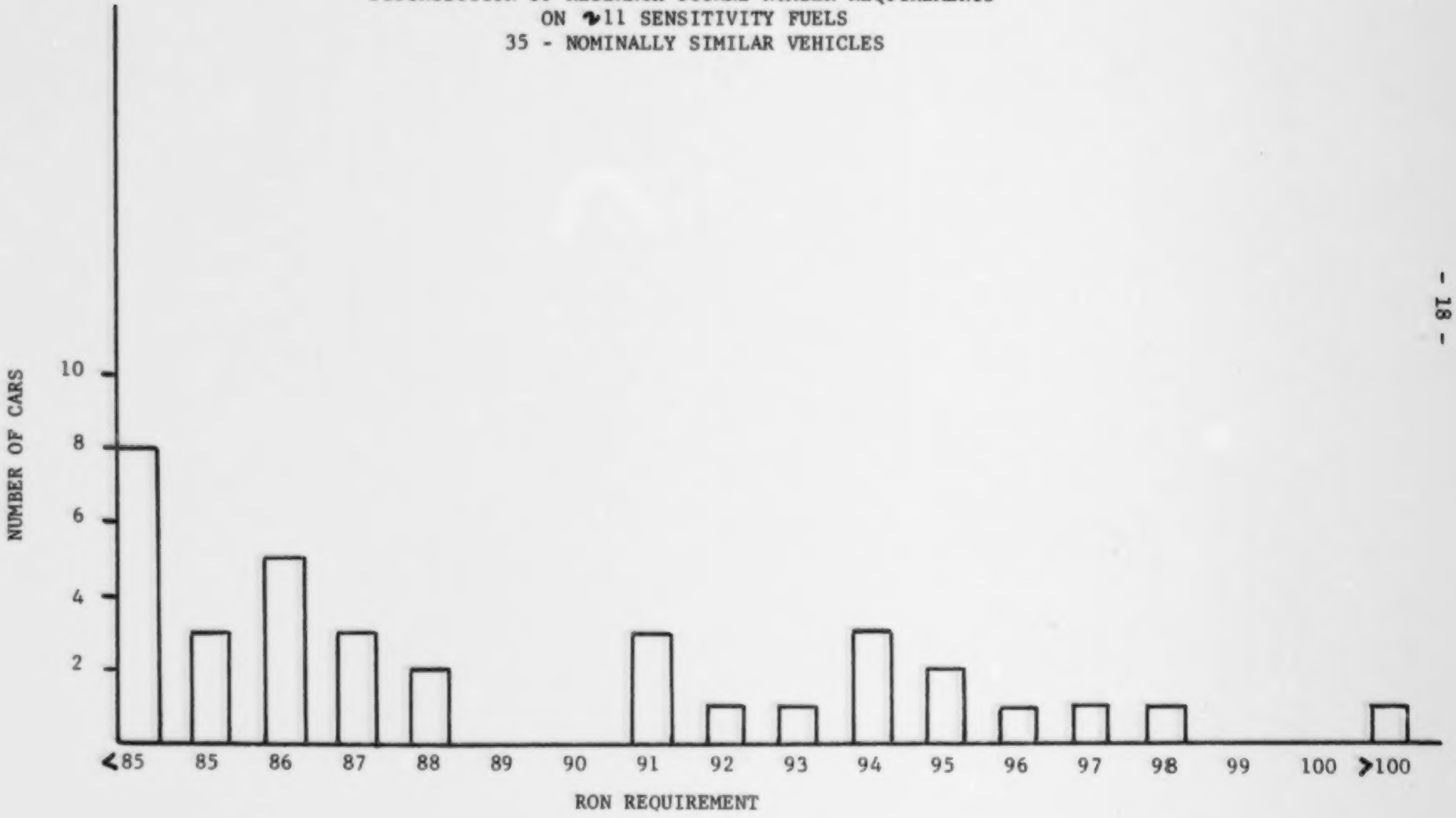


FIGURE 1-7

DISTRIBUTION OF
MAXIMUM RESEARCH O.N. REQUIREMENTS

ALL 1973 U.S. CARS INCLUDING IMPORTED MODELS (491 CARS)

PRIMARY REFERENCE FUELS ———————— :491 CARS
UNLEADED FUEL-8 SENSITIVITY - - - - - - - - :491 CARS
UNLEADED FUEL-11 SENSITIVITY —— —— —— :447 CARS
LEADED FUEL-6 SENSITIVITY —— · —— · —— :447 CARS

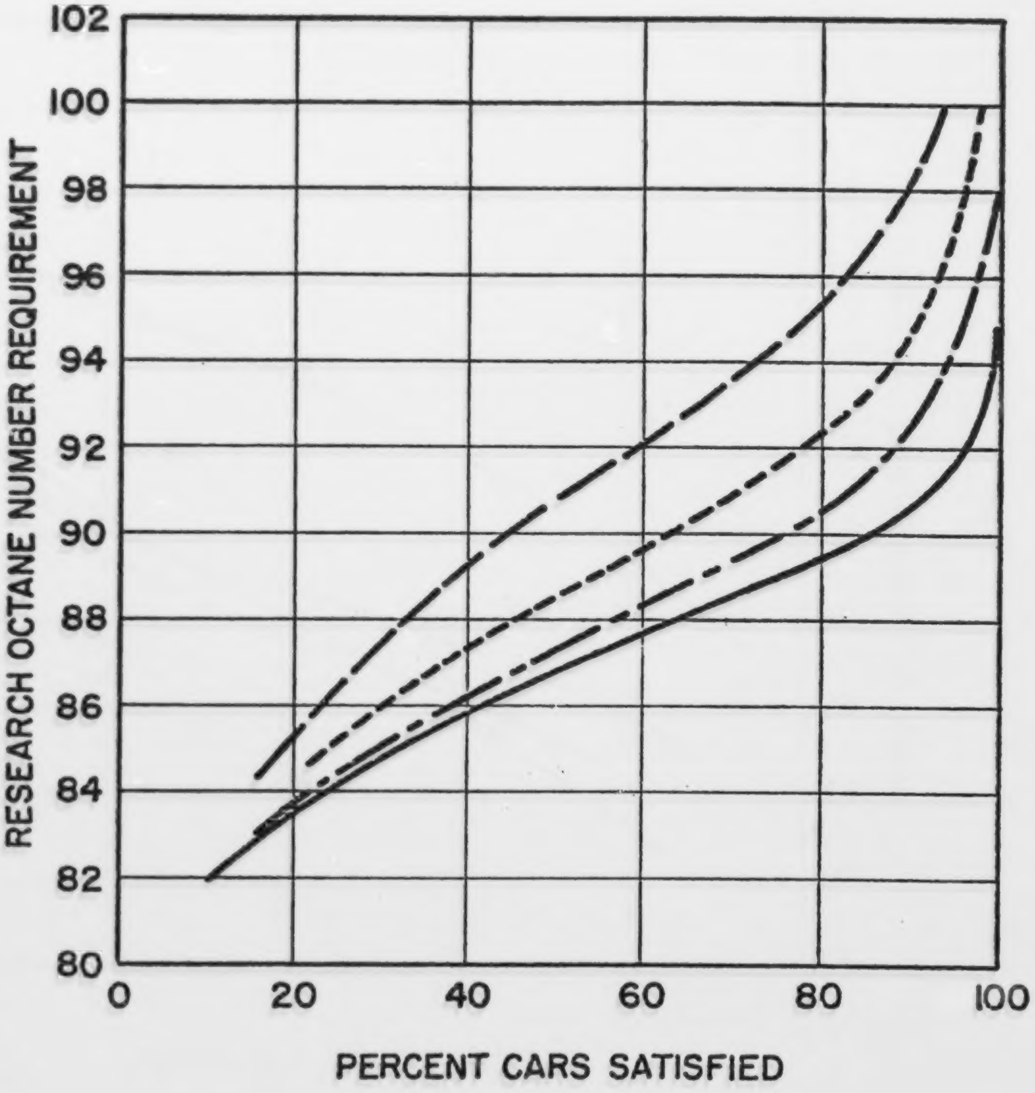
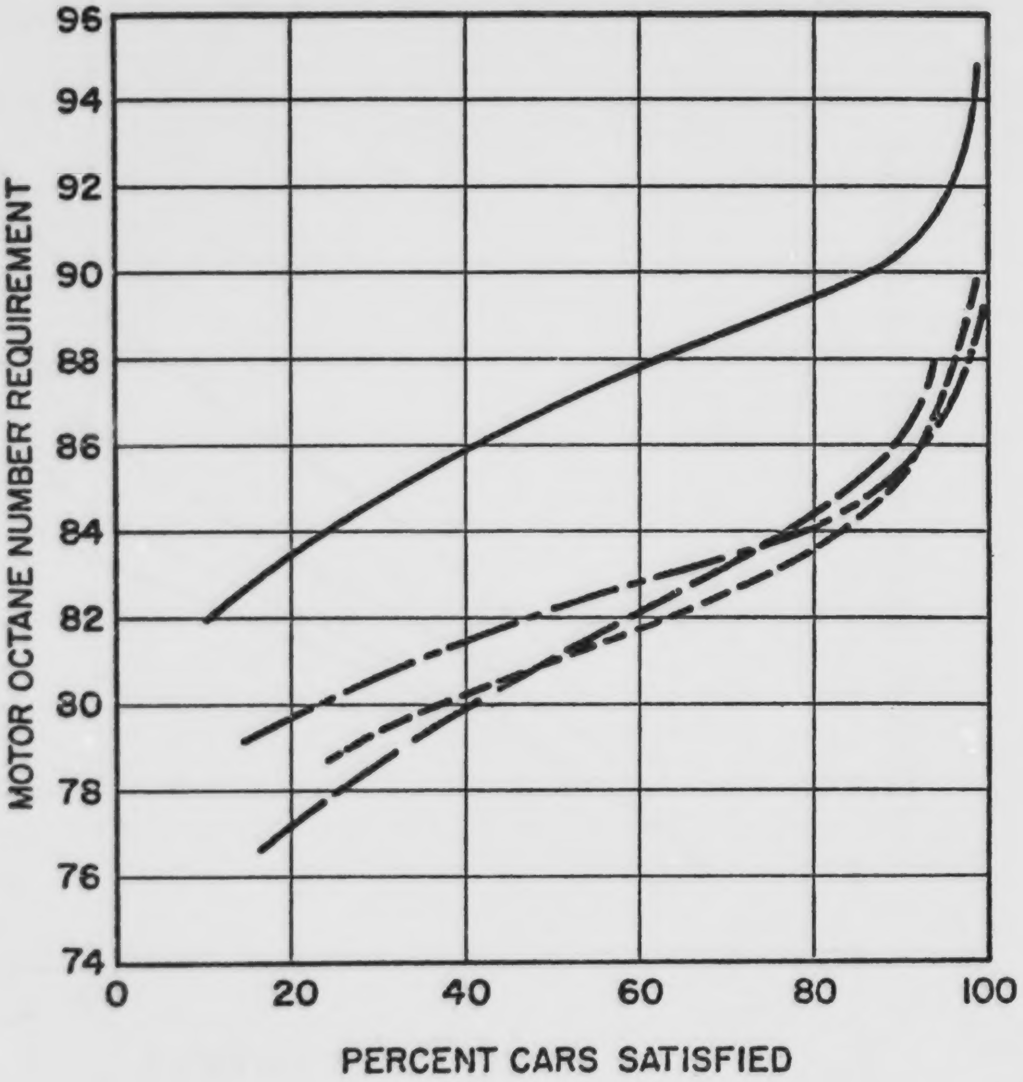


FIGURE 1-8

DISTRIBUTION OF
MAXIMUM MOTOR O.N. REQUIREMENTS

ALL 1973 U.S. CARS INCLUDING IMPORTED MODELS (491 CARS)

PRIMARY REFERENCE FUELS ———————— :491 CARS
UNLEADED FUEL-8 SENSITIVITY - - - - - - - - - :491 CARS
UNLEADED FUEL-11 SENSITIVITY — — — :447 CARS
LEADED FUEL-6 SENSITIVITY — · — · — · —:447 CARS



1.2 EXXON RESEARCH AND ENGINEERING APPROACH

The approach taken at ER&E was as follows. A standard 8:1 C.R. 350 CID Chevrolet Nova (California) was tested for tailpipe and evaporative emissions, fuel economy, octane requirement, performance, and driveability. These tests were made with a clean engine and again following 12,000 miles of deposit accumulation to stabilize octane requirement.

The vehicle was then modified to obtain a 9:1 C.R. using 1969 high compression heads coupled with the standard 1975 engine block. Emissions were recalibrated to the 8:1 C.R. level primarily by adjusting EGR flow to lower the higher NO_x emissions obtained at the 9:1 C.R. level. The big effort was in finding a suitable technique for reducing the vehicle's increased octane requirement. Several approaches were examined. These were:

Increased Turbulence - A greater amount of turbulence was generated using the 1969 heads, which have 30% greater squish area, together with head spacers to keep the compression ratio the same as the base case.

Shorter Combustion Duration - As discussed in this section, dual spark plug ignition increases engine power output and NO_x emissions by combining this approach with charge dilution or spark retard, comparisons were made at a dual ignition power output equivalent to that of the single ignition case.

Aluminum Heads - Because of their better heat transfer properties, aluminum heads were compared to cast iron heads for effects on octane requirement.

Controlled Spark Retard - Spark retard, applied only when detonation occurs, can be effective at reducing knock while not having a deleterious effect on vehicle emissions, fuel economy, and performance.

A key element in the development of such a system is the ability to sense knock or detonation. Knock sensing has been studied by several investigators using pressure transducers and vibration sensors.(18-23) In fact, it is routinely used in the Research and Motor Octane methods of measuring fuel octane quality. In such single cylinder engine tests, the combustion chamber pressure behavior with time exhibits characteristics unique to detonation which can conveniently be measured. On a vehicle with a multicylinder engine, it would be very costly to use sensors in each cylinder. A more desirable device is one which can be mounted externally to the engine and can sense detonation irrespective of the cylinder in which it occurs. Keller, et al.,(21) used a vibration sensor mounted on the engine intake manifold to develop an automated technique for the octane rating of fuels. Using this technique, they found the predominant knock frequency to occur between 4 and 6 kHz for most cars examined. In the present work, the optimal location of an accelerometer used to measure detonation-induced vibration of the engine was determined. The signal from the accelerometer was then used to trigger the spark control circuit to retard the timing when detonation occurs.

This latter approach of applying a temporary spark retard when detonation occurred, as detected by a knock sensor, and removing the retard quickly, showed the best results in the engine dynamometer evaluation. This approach was used to complete the modification of the 9:1 C.R. vehicle. The 9:1 C.R. vehicle was then tested in the same manner as was outlined for the 8:1 C.R. base vehicle.

SECTION 2

CONCLUSIONS

A 1975 350 CID (California) V-8 Chevrolet Nova with 8:1 C.R. was tested to determine emissions, fuel economy, octane requirement, performance and driveability before and after 12,000 miles were accumulated. The engine was then cleaned of deposits and modified to achieve a 9:1 C.R. by using 1969 high compression heads. At the higher compression ratio, the vehicle achieved 6% better fuel economy. The higher NO_x emissions at the 9:1 C.R. were reduced to the base level by substituting a back-pressure-modulated EGR unit for the original valve and increasing the EGR flow. Several techniques, outlined below, were examined to try to reduce the octane requirement of the 9:1 C.R. vehicle.

Increased Turbulence

Increased turbulence was generated by increasing the squish area by 34% over the base case 8:1 C.R. engine. This was accomplished by using 1969 350 CID cylinder heads coupled with the 1975 engine block and inserting head spacers to obtain an 8:1 C.R. The results showed that the increased squish area did not appreciably reduce octane requirement. If anything, the octane requirement was higher for the increased squish area engine. No effect of this squish area change on fuel economy or emissions was noted.

Dual Spark Plug Ignition

A second spark plug was inserted in the squish area of each cylinder directly opposite the primary spark plug. By firing two plugs, combustion duration is shortened. With dual ignition, power output, NO_x emissions, and octane requirement increased. When spark retard was used to lower the power output of the dual ignition case to that of the single ignition base case, octane requirement was lowered but was still higher than the single ignition case. NO_x emissions were lower than the base case. When EGR was used to lower the power output, similar results were obtained. However, EGR was not quite as effective as spark retard in regard to lowering the octane requirement.

Aluminum Heads

An attempt to compare aluminum with cast iron cylinder heads was made to see if aluminum gave any octane requirement reduction due to its better heat transfer characteristics. An exact comparison could not be made because the aluminum cylinder heads were quite different in design to the cast iron heads although both gave 9:1 C.R. when coupled with the 1975 block. These aluminum heads gave a 4 octane number lower requirement when compared to the cast iron heads.

Knock-Sensor Activated Spark Retard

A system was developed which temporarily retards the spark timing when knock is detected by an accelerometer and associated electronics. The knock sensor is attached to the cylinder head of the engine. When knock occurs, the vibration is picked up by the sensor, the signal is filtered to remove some of the engine background noise, and the knock pulse is detected. When the amplitude of the detected knock signal exceeds a threshold, the spark timing is retarded. When no knocking is detected over a waiting period, the timing is advanced back to its normal schedule. Using this system, the engine's octane requirement can be lowered several numbers with little loss in accleration performance or deterioration of emissions or fuel economy. This approach seemed to have the most promise and was subsequently installed on the vehicle.

When the system was installed on the vehicle, the following was shown:

(1) By mounting the sensors (piezoelectric quartz accelerometers) in various engine locations, the optimal location and the frequency of knock were determined for this engine type.

(2) The knock sensor-actuated spark retard system was capable of detecting detonation and reducing its intensity.

(3) Utilization of long delay periods before advancing the spark timing after a retard results in excellent reduction of detonation but very long acceleration times. Shorter delay times combined with lower trigger thresholds give good knock reduction and reasonable acceleration performance.

(4) Emissions and fuel economy testing using fuel that produces trace knock on WOT accelerations does not cause spark retard on the FTP and HFET cycles, thus not affecting fuel economy or emissions on those cycles.

Two alternate engines were also tested to see if the frequency of knock changed. The results showed that for a 2.3 liter 4-cylinder and a 2.8 liter V-6 engine, the frequency of knock was different than the 350 CID V-8 engine. However, for each engine a frequency region could be identified where knock could be distinguished from engine noise. Using the data and with appropriate filtering and electronics, a similar system could be built which would detect knock and actuate spark retard.

SECTION 3

RECOMMENDATIONS

Several approaches were used during the course of this work to try to reduce vehicle octane requirement. Recommendations for future work in areas are given below.

Increased Turbulence

In our work, a 35% increase in squish area showed little effect on octane requirement, emissions, or fuel economy. Any future study should focus on even more drastic changes in the shape of the combustion chamber. Additionally, several different designs need to be evaluated in order to reach a meaningful conclusion.

Dual Spark Plug Ignition

When dual ignition was employed, octane requirement increased over the base single ignition case, at least for the particular engine and spark plug locations which were chosen. Future work in this area might be expanded to examine several different designs with various secondary plug locations. It is possible that an octane requirement benefit can be realized if the right combustion chamber geometry and plug locations are chosen. When the torque was equalized for the single and dual ignition case by retarding the spark timing or by adding diluent (EGR), a NO_x benefit was observed for the dual ignition case. This is an interesting effect which might be exploitable to reduce vehicle NO_x emissions. Nissan has published work on their fast burn engine which uses dual spark plug ignition and heavy EGR which shows marked reduction in NO_x emissions.(25)

Aluminum Head Work and Better Heat Transfer

An attempt was made to compare aluminum and cast iron cylinder heads to see if aluminum's better heat transfer characteristics could be translated into a lower octane requirement. Due to differences in head design, a good comparison could not be obtained, making the results inconclusive. To make a meaningful comparison, identical cylinder heads need to be made and compared using the same block, intake manifold and carburetor. Due to valve train misalignment in the aluminum head engine, the test had to be terminated before a deposit-equilibrated engine could be octane rated. Comparison of octane requirement at equilibrium conditions is a necessity, because it may have a strong influence on any octane requirement differences noted between the two head materials.

In a slightly different vein, better heat transfer in the squish area of individual cylinders could have a beneficial effect on octane requirement. In addition, studies have shown that an individual cylinder may have a significantly higher octane requirement if it is not cooled properly. If this is the case, i.e., one cylinder has a high requirement, and the others have a lower requirement, the higher octane gasoline is being wasted for all but one cylinder. A study could be directed at determining the requirements of individual cylinders in an engine and making modifications as necessary to insure that no single cylinder has insufficient cooling. This approach would only be useful if the problem is of sufficient magnitude that an appreciable octane benefit can be realized. The solution to the problem should also be generally applicable.

Knock Sensor-Actuated Spark Retard

This study clearly demonstrated the benefits obtainable from a knock sensor-controlled spark retard system and also touched on some of the performance tradeoffs involved. No further work in this area is justified at this time except where evaluation of manufacturer's knock sensor systems is desirable. If a system evaluation is made, an ability to obtain a cumulative knock intensity rating may be very useful. As shown in our work, it is very difficult to octane rate a vehicle with an operational spark retard system because several intensities of knock are heard during accelerations. A good way to do the rating is on the basis of cumulative knock during the entire acceleration. This is difficult to do audibly but it may be possible to do electronically by using the existing knock sensor signal. An instrument similar to that discussed above would be very useful in octane rating vehicles with knock sensor-spark retard systems.

During the course of this work, several problems arose with the application of knock sensor-spark retard technology. These are discussed below to provide guidance for future work in this area.

Performance Debits - There are significant acceleration performance debits associated with using spark retard to eliminate most of the knock for several octane numbers below the engine's normal requirement. While a 2 to 4 octane number benefit was shown, 10-30% slower acceleration times were obtained. When long spark advance delay times were employed however, limited testing indicates that if slightly higher levels of detonation are allowed, much lower performance debits are possible (on the order of 0-10% depending on how much detonation is permitted). This can be accomplished by raising the threshold so that the system is less sensitive to detonation, by decreasing the waiting period before advancing the spark schedule or by some combination of the two. Another technique to improve overall performance would be to sense the end of an acceleration, with an additional engine input, after which normal spark advance would be used. For example, use of a manifold vacuum or throttle position indicator would provide a signal whereby the end of an acceleration is well characterized, i.e., high manifold vacuum or closed throttle. This signal could be used to override the spark control system to immediately cut out any applied spark retard under conditions similar to these, thereby reducing excessively long periods of applied retard even though a long spark advance delay is used.

Spurious Retard - Occasionally, spurious retards were noted during the course of this work. Some of these were well defined extraneous electrical interference which could be corrected, such as moving any unnecessary AC-operated electronics out of the car, using DC-power for the controller itself, and removing tachometer leads from car. Others were ignored because they were not considered to be serious uncorrectable problems in a commercial unit, e.g., spark retards when cranking starter motor to start the engine. A more serious problem, which manifested itself just prior to replacing the cylinder heads with recessed valves, was that real engine noises other than knock could trigger the spark retard system occasionally. These retards were traced by listening to tape recordings slowed down to 1/16 of normal speed. In these recordings, knock is very apparent as a ringing drum-like sound and valve noises can be distinguished from it. A peculiar valve noise, which had some ringing character to it, occasionally produced a retard. These spurious retards could be eliminated by raising the threshold at the expense of lower sensitivity to knock. These 1969 heads were not induction hardened. When severe valve recession had occurred, the heads were replaced. No retards of this type have since been noted.

Surface Ignition - The accumulation of ashy oil-based deposits (40-50% ash) in the combustion chamber caused a significant surface ignition problem during one phase of the study. In fact, when the heads were removed, a large ashy particle was removed from the cylinder which had been knocking. In this case, spark retard actually made the surface ignition much worse, presumably due to the increased generation of heat in the engine. This would probably not be a general problem since surface ignition is rare with unleaded fuel. In this case, the severe driving schedule, i.e., more WOT accelerations, may have produced the high ash deposit problem due to high oil consumption.

Engine Overheating - Although tests were not made, the potential exists for engine overheating with long periods of running with retarded timing. This could occur either by a malfunction of the spark control system or by the use of a fuel of much lower octane quality than the engine's requirement. For this reason (and also for putting a limit on acceleration performance losses), only 10° maximum retard is allowed. This potential problem could probably be eliminated by using a coolant temperature sensor to override the spark retard system if high coolant temperatures occur.

SECTION 4

TESTING OF 8:1 C.R. BASE VEHICLE

4.1 TEST VEHICLE SELECTION

The feasibility demonstration of techniques to increase mechanical octane was, by the terms of the contract, to be carried out on a vehicle. The choice of vehicle was guided by the following factors. First, the car had to be compatible with modifications necessary to achieve increased mechanical octane. This meant that modification of the combustion chamber to increase 'squish' had to be achieved by off-the-shelf parts. The configuration of the cylinder head or heads had to allow insertion of a spark plug into the squish area of each cylinder for the evaluation of the dual spark plug technique to increase mechanical octane. Finally, the ignition system of the vehicle also had to be compatible with the proposed knock sensor actuated spark retard system.

The second factor taken into consideration in the choice of a test vehicle was related to the future trend in passenger cars. It was assumed that vehicle weights would decrease with successive model years in an effort to meet more stringent fuel economy standards. The 1975 Chevrolet Nova was chosen as typical of the large end of future passenger car lines. The engine of choice for the Nova was the 350 CID V-8, with an 8:1 compression ratio with no deposits. While it was felt that this power plant would be somewhat large in terms of future expectations, it had the advantage of having the flexibility for combustion chamber modifications with production parts more so than other candidate engines. With the approval of the Project Office, a 1975 production Chevrolet Nova with the 350 V-8 engine was purchased in California. This vehicle, equipped with an air injection pump and oxidation catalyst, was designed to meet the California Standard of 9.0 g/mile carbon monoxide, 0.9 g/mile hydrocarbons, and 2.0 g/mile nitrogen oxides. A complete vehicle description is given in Table 4-1.

4.2 BASELINE TESTING

Base tests of the vehicle consisted of octane rating, emissions testing and evaluation of driveability at the start and at various intervals during mileage accumulation. It was realized that during the course of accumulation and testing of the vehicle some catalyst deactivation could take place. Therefore, to compare the emissions characteristics of the modified vehicle to the base, fresh catalyst was to be used during testing of the demonstration vehicle. To eliminate any emission effects attributable to differences in catalyst used at various stages of the program, it was decided to obtain sufficient quantitites of a single batch of catalyst pellets from the original supplier, AC Spark Plug Division of General Motors, to be used in all phases of testing including the base vehicle tests.

TABLE 4-1

VEHICLE DESCRIPTION

1975 Chevrolet Nova (California)

Inertia Weight	-	4000 lb
Rear Axle Ratio	-	3.08/1
Transmission	-	3 Speed Automatic
Engine:		
Ignition Timing	-	6°BTC Basic Timing
350 CID Displacement		
4.00" Bore		
3.48" Stroke		
8.0:1 Compression Ratio		
Rochester M4MC 4 Barrel Carburetor		

Emissions Control System:
- Ported EGR System
- Thermostatic Air Cleaner
- Catalytic Converter
- Converter Air Injection
- Early Fuel Evaporation System

MILEAGE ACCUMULATION - Mileage accumulation was performed entirely on a dynamometer with an automatic driver responding to a magnetic tape input signal which dictated the driving cycle. This cycle consisted of city, suburban, and highway driving. The total cycle time was approximately five hours and forty minutes, covering a distance of 183 miles for an average speed of 32 miles per hour. This average speed is similar to that of the AMA durability cycle. Accumulation was on an around-the-clock basis with only one scheduled shutdown in a 24 hour period for normal maintenance checks.

The fuel used during mileage accumulation was blended from standard refinery streams to give a research octane number of 91 to 92 clear, with a sensitivity of about 9. Certain specifications on aromatic and olefin content set by the Project Officer also had to be met. The fuel sulfur content was adjusted to approximately 300 ppm by the addition of a mixture of three sulfur compounds consisting of 87% thiophene, 11% diethyl sulfide, and 2% ditertiary butyl disulfide. A commercial additive package was added to the fuel. Properties of the mileage accumulation fuel used during base vehicle testing are given in Table 4-2.

TABLE 4-2

MILEAGE ACCUMULATION FUEL PROPERTIES

Research Octane Number - 91.7
Motor Octane Number - 82.9
API Gravity @ 60°F - 57.2
Lead Content - <0.01 g Pb/gal.
FIA: Aromatics - 29.1%
    Olefins - 7.1%
    Saturates - 63.8%
Sulfur - 295 ppm
RVP - 9.13 psi
I.B.P. - 94°F
10% - 133°F
50% - 223°F
90% - 334°F
F.B.P. - 427°F

BASE VEHICLE EMISSIONS AND FUEL CONSUMPTION - Emissions and fuel consumption were measured on the 1975 Federal Urban Cycle (CVS-CH) and the highway fuel economy cycle (HFET) using high octane indolene clear. Measurements were made in triplicate at the start and end of accumulation and in duplicate at various intervals. Test results for emissions are given in Table 4-3. The vehicle had undergone several

TABLE 4-3

BASE VEHICLE EMISSIONS

Mileage	CO-g/mile		HC-g/mile		NO_x-g/mile	
	CVS-CH	HFET	CVS-CH	HFET	CVS-CH	HFET
564	2.97	0.41	0.47	0.35	2.64	3.75
585	3.73	0.14	0.54	0.22	2.39	3.71
606	4.42	0.27	0.70	0.13	2.30	3.53
6,860	3.47	0.50	0.41	0.28	1.77	3.34
6,882	4.09	0.53	0.39	0.24	1.84	3.34
8,903	4.34	0.27	0.49	0.14	1.80	3.81
8,925	4.96	0.37	0.43	0.20	1.61	3.36
11,025	6.16	0.70	0.48	0.23	2.33	4.58
11,046	4.96	0.31	0.49	0.14	2.02	3.71
13,148	4.32	0.62	0.49	0.21	2.23	5.73
13,170	4.33	0.68	0.44	0.17	2.18	4.74
13,191	5.50	0.71	0.51	0.23	2.34	4.93

hundred miles of driving, as the table shows, by the time mileage accumulation was initiated. This was due to the fact that the vehicle was first octane rated so as to obtain a clean engine requirement. After this initial octane rating, the catalyst bed was refilled with fresh catalyst and emissions testing was begun. From the repeat tests of Table 4-3, the variances of the test procedure can be calculated. The average emissions at start and end of mileage accumulation with the corresponding variances are shown in Table 4-4.

TABLE 4-4

EMISSION TRENDS WITH MILEAGE

	CO		HC		NO_x	
	CVS-CH	HFET	CVS-CH	HFET	CVS-CH	HFET
Average-g/mile:						
Start	3.71	0.27	0.57	0.23	2.44	3.66
13,000 miles	4.72	0.67	0.48	0.20	2.25	5.13
Variance	0.4396	0.01745	0.00464	0.00471	0.01614	0.1513

Certainly on the emissions cycle there is no clear trend of emissions with mileage. The indicated increase in CO is, in a statistical sense, significant at about 90% confidence. The increase observed in both CO and NO_x on the fuel economy cycle is highly significant. The vehicle readily met the standards of 9 g/mile CO and 0.9 g/mile HC but had nitrogen oxide emissions approximately 10% above the 2 g/mile standard at the end of mileage accumulation.

Early in the course of mileage accumulation, evaporative emissions were also measured from the base vehicle by the SHED test. Results are shown in Table 4-5 for three repeat tests. Total emissions were found to be relatively high, coming primarily from the hot soak portion of the test from leaks around the carburetor. In this vehicle the carburetor was not vented to the charcoal canister so that expanding vapors during the hot soak could escape only through any openings on the carburetor and air cleaner housing. Fuel vapors generated in the fuel tank such as is the case during diurnal cycling were reasonably well controlled by the tank vent to the charcoal canister.

TABLE 4-5

EVAPORATIVE EMISSIONS - GRAMS

Test	Diurnal Cycle	Hot Soak	Total
1	1.59	7.96	9.55
2	2.49	10.97	13.46
3	2.32	9.84	12.16

Estimates of fuel economy for the base vehicle were obtained from the carbon balance of the exhaust constituents and by weight of fuel consumed during the two test cycles. Fuel economy values for both test procedures were calculated from the total fuel consumed during each test and the miles driven. Data for the CVS-CH cycle shown in Table 4-6 are, therefore, not weighted like the emissions. Such weighted fuel economy data are, however, given for each test in Appendix B.

TABLE 4-6

FUEL ECONOMY OF BASE VEHICLE-MPG

	FROM EMISSIONS			FROM WEIGHT		
Miles	CVS-CH	HFET	COMBINED	CVS-CH	HFET	COMBINED
564	12.12	17.24	14.00	12.72	17.56	14.52
585	11.58	16.36	13.33	12.01	16.35	13.64
606	11.81	16.40	13.51	12.36	17.23	14.16
6,860	12.00	16.27	13.61	12.30	15.27	13.48
6,882	12.19	16.39	13.78	12.13	15.56	13.47
8,903	11.11	15.48	12.73	11.14	14.91	12.57
8,925	11.62	15.87	13.21	11.91	15.16	13.18
11,025	12.55	18.63	14.71	12.11	15.95	13.58
11,046	12.72	19.71	15.14	12.15	16.35	13.74
13,148	11.94	15.95	13.46	12.24	15.75	13.60
13,170	11.95	16.74	13.72	12.58	16.11	13.96
13,191	11.93	16.39	13.59	12.45	16.03	13.84
Averages:	11.96	16.79	13.73	12.18	16.02	13.64
Variances:	0.04423	0.2100	0.07091	0.08895	0.1439	0.09394

Inspection of the data in Table 4-6 shows there to be relatively little difference in the fuel economies measured from emissions and by weighing, nor is the variability significantly different from the two measurement techniques. The only discrepancies of note are on the fuel economy cycle at 11,000 miles. The fuel economies obtained from emissions at that point of testing were unusually high. By weight the results remained consistent throughout. No effect of mileage accumulation on fuel economy was found for the base car.

BASE VEHICLE OCTANE REQUIREMENT - Octane requirements were measured at the same intervals as exhaust emissions and are shown in Table 4-7. At both the beginning and end of mileage accumulation, ratings were made on the road and on the mileage accumulation dynamometer (MAD) with three fuel series: primary reference fuels, a full boiling range series of constant 8 sensitivity, and another full boiling range series of 11 sensitivity. The CRC rating procedure was used. Octane requirement at intermediate mileage points were determined only on the MAD with the eight sensitivity fuel series. As the ratings with the eight sensitivity series show, 'equilibrium' had been established by about

TABLE 4-7

OCTANE REQUIREMENT OF 1975 NOVA

Test Site	Mileage	PRF(2)	Research Octane Requirement CSU-8(3)	CSU-11(4)	RMFD 276-74
Road	121	79	79	< 86	< 84 (78.8 MON)
MAD(1)	278	84	84	< 86	84 (78.8 MON)
Road	425	81	82	< 86	< 84 (78.8 MON)
MAD	6,903		90		
MAD	8,960		88		
MAD	11,068		90		
Road	13,239	86	91	93	
MAD	13,411	86	91	92 (2.5 in. Hg. vac.) 93 (8 in. Hg. vac.)	
Clean Engine MAD	13,520	80	82	< 86	< 84 (78.8 MON)
Road	13,650	78	79	< 86	< 84 (78.8 MON)

---

(1) Mileage Accumulation Dynamometer
(2) Primary Reference Fuels
(3) Constant Sensitivity of $\sim$8
(4) Constant Sensitivity of $\sim$11

7,000 miles. The octane requirement increase, as measured on the road was 7 for primary reference fuels and 12 for the 8 sensitivity fuel series. Whereas initially the engine was sensitive only to the research octane number of the fuel, as shown by the ratings at 278 miles, the final road rating indicates that the motor octane number had become the more important fuel property. In terms of full boiling range fuels, the deposit stabilized vehicle is satified by 91 RON-82.7 MON and also by 93 RON-81.6 MON. Accordingly, a change of two research octane numbers is compensated by a change of 1.1 motor number. The vehicle, therefore, 'appreciates' 35%of the RON and 65% of the MON of the fuel.

The octane requirement increase (ORI) experienced by the base vehicle was large compared to historical experience. To determine if this ORI was due entirely to deposit buildup, the combustion chambers of the engine were physically cleaned to remove deposits from the cylinder heads and piston tops. Clean engine ratings on both the MAD and on the road showed the octane requirement to be the same again as at the start of mileage accumulation. The measured ORI of 12 numbers was, therefore, entirely attributable to combustion chamber deposit buildup.

DRIVEABILITY AND PERFORMANCE - After completion of mileage accumulation, the vehicle was tested for acceleration performance on the test track normally used for road octane rating. Two types of tests were run: 0-60 MPH full throttle accelerations and elapsed time for the quarter mile from a standing chart. Results are given in Table 4-8.

TABLE 4-8

ACCELERATION PERFORMANCE OF BASE VEHICLE

A) 0-60 MPH	Direction	Time-sec.
	South	11.20
	"	11.40
	"	11.70
	"	11.45
	Ave. South	11.44
	North	10.65
	"	11.05
	Ave. North	10.85
	Ave. excluding wind	11.14

B) Quarter Mile		Time-sec.
		18.1
		17.5
		17.6
	Average	17.7

Driveability tests were carried out on a chassis dynamometer with four fuels blended to varying volatility characteristics as given in Table 4-9. The four fuels were blended to give low front end volatility with low and high midfill. Front end volatility affects ease of starting. Midfill volatility determines the driveability before the engine has reached operating temperature. The four fuels, therefore, were blended to determine how critical the vehicle is to these fuel variables. All rating tests were run at 70°F. Both the 'cold start-driveaway' and the "warm vehicle" evaluation of the CRC procedure were run on each of the four fuels. With the exception of occasional hesitation during part throttle acceleration and a stall during a wide open throttle acceleration with fuel D-3, driveability was generally rated as satisfactory on all fuels. Detailed results of these tests are to be found in Appendix D.

TABLE 4-9

PROPERTIES OF DRIVEABILITY FUELS

	D-1	D-2	D-3	D-4
Reid Vapor Pressure, psi	7.03	6.87	11.92	11.18
% (D+L)* @ 158°F	9.9	10.0	25.8	32.5
" @ 212°F	47.7	65.7	46.5	64.5
" @ 302°F	87.9	92.9	85.5	93.5
RON	93.5	94.2	98.2	95.0
MON	86.4	85.3	86.9	85.9

---

* (D+L) is the sum of the portion of fuel distilled and the loss.

SECTION 5

LABORATORY EVALUATION OF MEANS TO ACHIEVE ADDITIONAL MECHANICAL OCTANE

Four independent techniques for reducing engine octane requirement were examined in this work. These were: 1) increased turbulence through the use of higher squish area heads, 2) shortened combustion duration through the use of two spark plugs per cylinder, 3) better heat transfer characteristics of the head material obtained through the use of aluminum heads, and 4) controlled spark retard actuated by a knock sensor. These four approaches were evaluated in an engine dynamometer installation with a 350 CID engine. They are discussed in detail below. The most promising approach proved to be the knock sensor-actuated spark retard which imposed a temporary retard in response to knock. This technique was then used to control the octane requirement of the vehicle modified to obtain a 9:1 C.R.

5.1 ENGINE EVALUATION OF INCREASED SQUISH COMBUSTION CHAMBERS

By the provisions of the contract, the techniques for increasing mechanical octane were to be evaluated on an engine dynamometer using the engine of the demonstration vehicle. After completing base vehicle testing, the engine was removed from the Chevrolet Nova and transferred to an engine cell. The first of the three techniques to be evaluated was the use of increased squish areas in the combustion chamber. As has been previously pointed out, one of the chief reasons for selecting the NOVA with the 350 CID V-8 engine as the test vehicle was the possibility of evaluating the effect of squish with off-the-shelf hardware. Cylinder heads and pistons of high compression ratio versions of this engine from earlier years were readily interchangeable with the basic block of the 1975 engine. The heads from the 1969 engine, which in combination with flat-topped pistons, gave a nominal compression ratio of 11.25:1 had larger squish areas than the 1975 heads. This made it relatively easy to test this concept without modifying either pistons or heads of the 1975 engine. Figure 5-1 is a schematic drawing, to scale, of sections of the 1975 and 1969 cylinder heads showing the squish areas as shaded zones. The squish areas in the 1969 heads are approximately 34% larger than in the 1975 heads. Over half of this increase comes from the extra squish area behind the spark plug.

The compression ratio of the base engine, nominally 8.5:1 with deposits, was determined from the piston displacement and from measurements of the combustion chamber volume at the top dead center position of the piston. With a clean combustion chamber the compression ratio was found to be 8.0:1. Similar measurements using the 1969 heads

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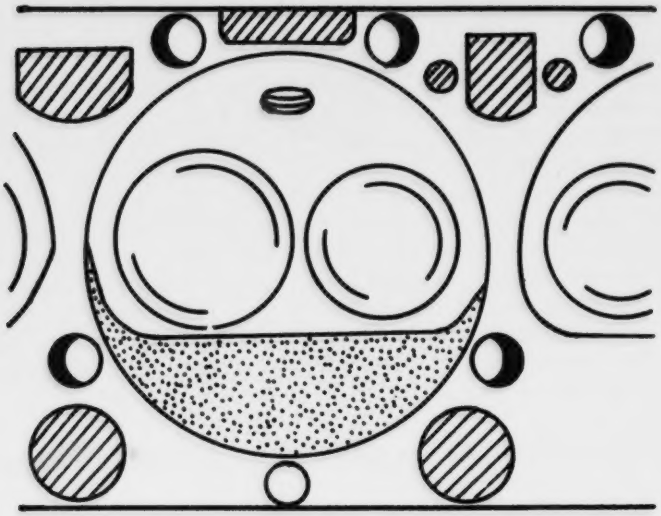
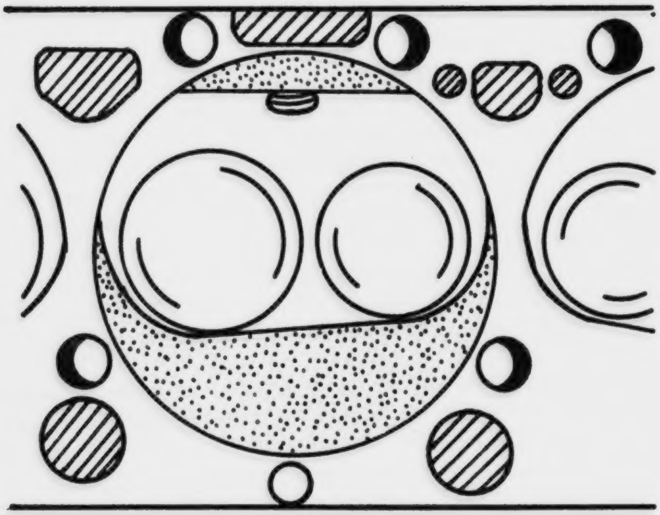
FIGURE 5-1 Top View of 350 CID Cylinder Heads

1975 HEAD



1969 HEAD



in conjunction with the 1975 block gave a compression ratio of 9.0:1. It was possible to make a comparison of the octane requirement of the two combustion chamber configurations at the same compression ratio, 8.0:1, by using the 1969 heads together with a head spacer of 0.045 inches thickness and two standard gaskets. The squish thickness, i.e., the thickness of the gap between piston top and that part of the head surface which is shaded in Figure 5-1, was of course greater with the 1969 heads. Results of the octane requirement comparison are shown in Table 5-1 with results from the base vehicle tests for comparison.

Table 5-1

Octane Requirement with Squish Area Variation

	PRF*	CSU-8**	Test Conditions
1975 Heads, C.R. - 8:1:	79	79	Road, 120 Miles
	86	91	Road, 13,200 Miles
	78	79	Road, 13,500 Miles, Clean
	80	78	Eng. Cell, Manual Operation
	78.5	79	Eng. Cell, Automatic Operation
1969 Heads, C.R. - 8:1:	81	81	Eng. Cell, Automatic Operation
1969 Heads, C.R. - 9:1:	90	91	Eng. Cell, Automatic Operation

* Primary reference fuels
** Full boiling range fuels with sensitivity of 8.

Octane rating in the engine cell was carried out in high gear during full throttle accelerations from 30 to 70 MPH. Road rating of the base vehicle had shown that it was full throttle limited. Loading of the engine during the accelerations was initially performed by manual control to give acceleration times during rating of about 15 to 20 seconds to go from 30 to 70 MPH in high gear. In later testing the engine was automatically loaded by a closed loop load control system which adjusted the load as a function of velocity and acceleration rates. Comparison of clean engine requirement obtained on the road with the base vehicle and ratings of the base engine in the engine cell (Table 5-1) show that the engine rating procedure simulated road performance very well.

Engine cell data of Table 5-1 at a compression ratio of 8:1 show that the 1969 heads with the higher squish area gave a two number higher octane requirement with primary and full boiling range fuels. This increase, while undoubtedly real, was not further investigated. Higher end gas temperatures in one or more cylinders of the high squish heads, perhaps due to poorer cooling system circulation, is only one of several explanations consistent with the unexpected observation of increased octane requirement with the higher squish area heads.

Despite the absence of any beneficial effect of increasing squish area, the engine was retested with the 1969 heads at a 9:1 compression ratio. At this compression ratio, obtained without the use of the head spacer, the squish thickness was identical to that of the base engine with the 1975 heads. The one number increase in compression ratio resulted in an increase of nine octane numbers in clean engine primary reference fuel requirement, a surprisingly large effect.

The effect of the various cylinder head configurations on fuel consumption was measured on the Federal Urban Emission Cycle. Operation on this or any arbitrary cycle was made possible by an "automatic cycle follower" control system. With this system, the engine throttle is automatically driven from a magnetic tape of speed as a function of time to give the desired "vehicle speed" as a function of time through a closed loop controller which compares actual speed to the desired speed. The load is also adjusted by a closed loop controller as a function of velocity and rate of acceleration. Fuel consumption data are given in Table 5-2. The results show that the standard engine consumed 8 to 9% more fuel in the engine cell than in the vehicle on the chassis dynamometer. The comparison of the standard heads and 1969 heads at an 8:1 compression ratio gave no statistically significant difference. The effect of increasing the compression ratio from 8:1 to 9:1 reduced the fuel consumption significantly. In the cold start test cycle the reduction amounted to 6.5% combined for the three bags. For the same test cycle but with hot starts the reduction in fuel consumption averaged 5.8%. An effect of this magnitude is not unexpected for the indicated change in compression ratio.

Emission effects are compared in Table 5-3. In the absence of a constant volume sampling system, it was not readily feasible to obtain mass emissions for cyclic operation. In order to obtain an indication of the effect of combustion chamber configuration on emissions, the continuous traces of CO, HC, and NO_x emissions were time averaged on the urban emission cycle. The catalyst-out emissions for carbon monoxide and hydrocarbons of Table 5-3 are strongly influenced by the startup 'quality' of the engine and are therefore subject to considerable variation. The increase of hydrocarbon emissions commonly claimed when the compression ratio is increased is by no means obvious from these results, at least not after the catalyst. However, even a cursory glance at the continuous trace of nitrogen oxide emissions showed that the NO_x emissions are significantly higher in the 9:1 compression ratio tests. The data of Table 5-3 suggest the effect to be an approximately 50% increase in NO_x when going from 8:1 to 9:1 compression ratio.

As a result of the discouraging data on the effect of increased squish area on octane requirement, that approach was abandoned. While still more drastic changes in combustion chamber shape than those tried in this study might reduce octane requirement, the construction of the necessary hardware was beyond the scope of this contract.

Table 5-2

Fuel Consumption with Squish Area Variation

	Fuel Used - Pounds			
	Cold Start		Hot Start	
	Bags 1&2	Bag 3	Bags 1&2	Bag 3
Chassis Dynamometer:				
Standard Vehicle	4.12	1.69		
Engine Dynamometer:				
Standard (C.R.=8:1):	4.36	1.85	4.14	1.96
	4.40	1.83	4.07	1.90
	4.58	1.87	4.00	1.86
Average	4.45	1.85	4.07	1.91
1969 Heads (C.R.=8:1):	4.45	1.83	4.13	1.87
			4.11	1.87
			4.10	1.84
Average	4.45	1.83	4.11	1.86
1969 Heads (C.R.=9:1):	4.14	1.73	3.89	1.76
			3.84	1.75
			3.89	1.75
Average	4.14	1.73	3.87	1.75

Table 5-3

Hot Start Emissions with Squish Area Variation

	Time Averaged Concentrations					
	CO-%		HC-ppm C_6		NO_x-ppm	
	Bags 1&2	Bag 3	Bags 1&2	Bag 3	Bags 1&2	Bag 3
Standard (C.R.=8:1);	0.22	0.22	29.6	38.0	249	396
1969 Heads (C.R.=8:1):	0.18	0.09	26.9	19.2	266	388
1969 Heads (C.R.=9:1):	0.13	0.07	33.1	12.4	415	596

5.2 DUAL SPARK PLUG IGNITION

One technique used to try to lower the engine's octane requirement was minimization of the time required for the flame to travel through the combustion chamber. This can be accomplished by utilizing two spark plugs in each cylinder. By igniting the air-fuel charge both by the normal spark plug and by one located in the end-gas region, hopefully the end-gas volume would be minimized before autoignition can take place.

This approach was attempted by modifying a set of both 1975 and 1969 350 CID heads to accept an additional spark plug in the squish area of each cylinder. A photograph of a modified 1969 head is given in Figure 5-2 showing the location of the primary (normal) and secondary spark plugs. In all of these tests, the secondary spark plugs were always located in the end-gas region directly opposite the primary spark plug. In addition to the head modification, a special dual distributor had to be built to permit independent firing of both plugs. This distributor is shown in Figure 5-3.

When the engine was first fired up, there was a serious problem of cooling fluid leaking past the seals of the secondary plugs into the combustion chamber. This problem could not completely be eliminated in the case of the 1975 heads, but satisfactory results were obtained with the 1969 heads modified with the dual spark plug system. A schematic showing the alignment of the secondary plug through the water jacket into the cylinder is given in Figure 5-4. A high temperature sealant was used at the threads and the seats of each of the secondary plugs to isolate the cooling system from the combustion chamber. These secondary plugs, obtained from Champion, operated satisfactorily when assembled in this manner.

EFFECT OF DUAL IGNITION ON TORQUE AND SPEED - The effect of dual ignition on torque at the automatic transmission output shaft was measured at a speed equivalent to 40 mph with the transmission in high gear.

Table 5-4 - Effect of Dual Plugs on Torque

		Transmission Output Shaft	
Firing Mode	Engine rpm	Torque - Ft. Lbs.	rpm
Standard Plugs	1685	65	1585
Standard and Secondary Plugs	1885	73	1590

FIGURE 5-2

DUAL SPARK PLUG IGNITION ENGINE

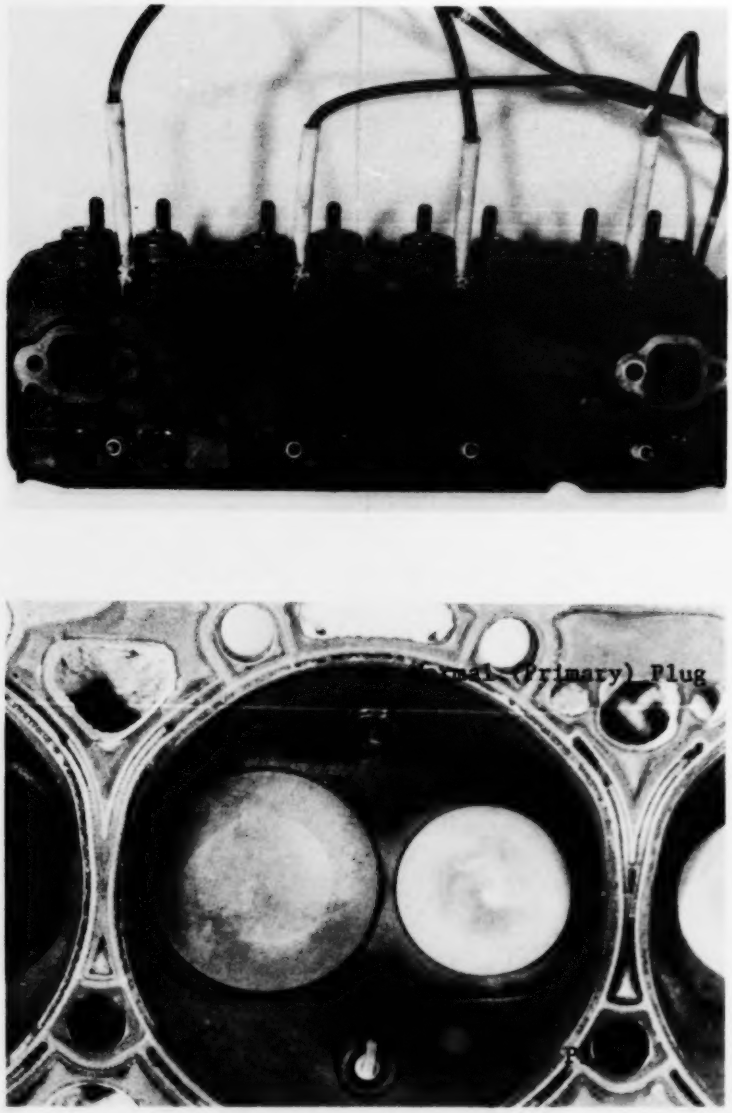

rmal (Primary) Plug
P

FIGURE 5-3

DUAL SPARK PLUG DISTRIBUTOR

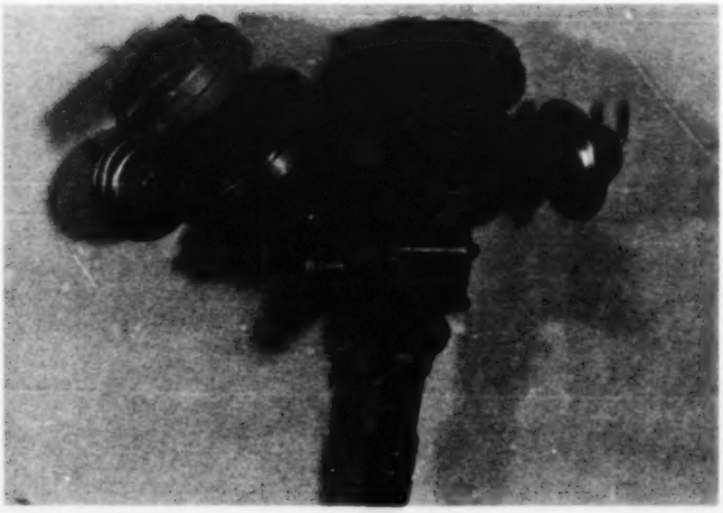
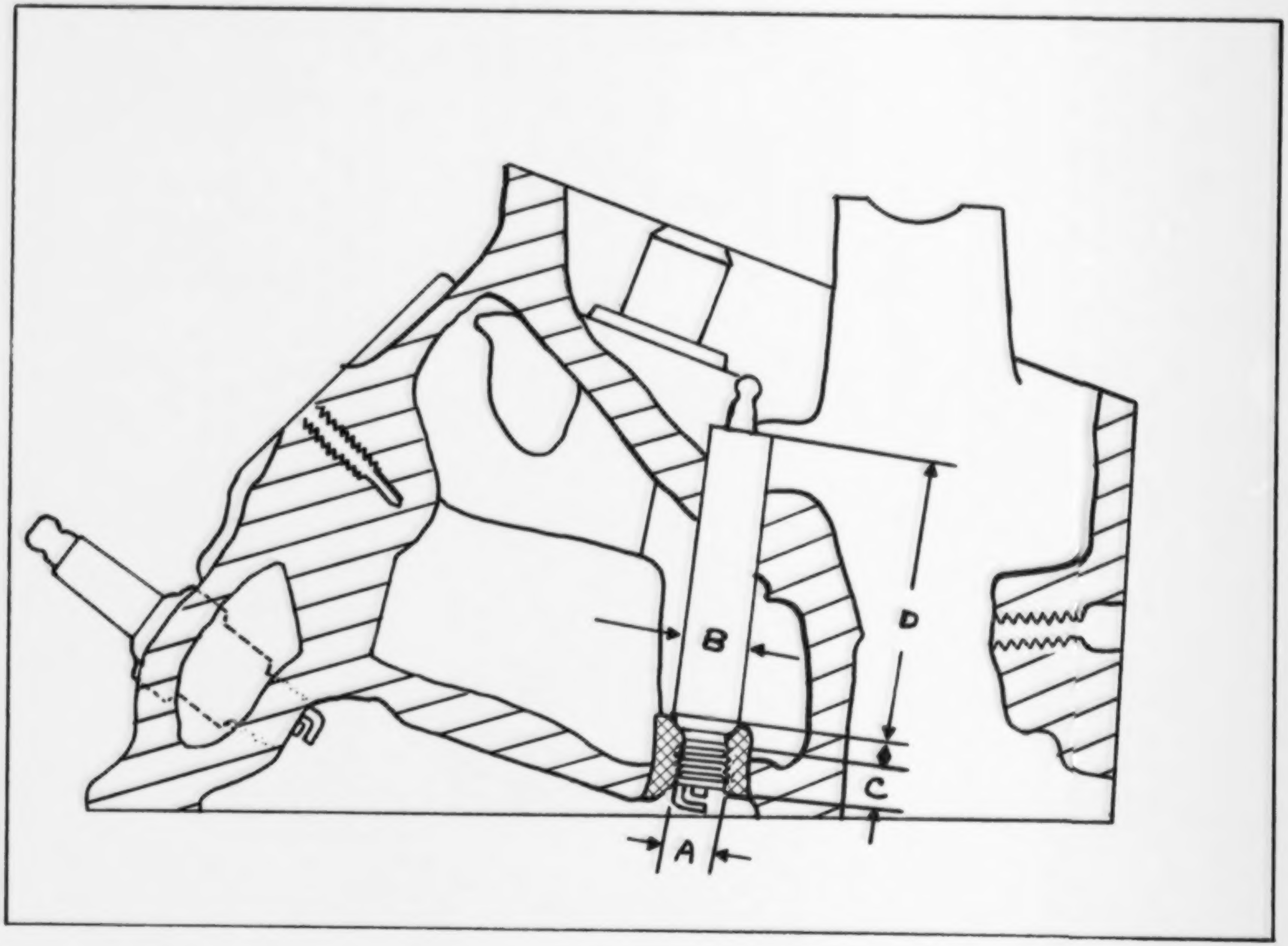


FIGURE 5-4

DUAL SPARK PLUG CONFIGURATION



In the comparison made in Table 5-4 the only change made was in the number of spark plugs firing per cylinder. The throttle position remained unchanged and the spark timing was set at 6°BTDC basic on both primary and secondary plugs. The output shaft speed of the transmission was being held constant by the dynamometer. With both plugs firing simultaneously, torque or power output increased by over 12% at the output shaft of the automatic transmission.

At a somewhat higher output shaft speed the power output was compared for firing with the primary plugs only, the secondary plugs only, and both simultaneously.

Table 5-5 - Torque with Different Firing Modes

Firing Mode	Engine rpm	Transmission Output Shaft Torque - Ft. Lbs.	Transmission Output Shaft rpm
Primary	1890	45	1831
Primary and Secondary	2000	50	1830
Secondary	1940	36	1818
Primary and Secondary	2050	51	1832

Table 5-5 shows the preferred firing arrangement in terms of power output. Again with dual ignition output shaft power is 12% greater than firing with the standard plugs only. It is clear from the table that firing with the primary plugs by themselves is more effective than firing only with the secondaries. Igniting the charge in the squish area gave about 20% less power than igniting the mixture at the standard location opposite the squish zone.

The effect of dual spark plug ignition on torque was measured at several different speed-load combinations with isooctane to avoid knocking and a standard transmission to minimize transmission power losses. These comparisons were made at 10" manifold vacuum at 1500, 2000, 2500, and 3000 rpm. Additionally, tests were run at 2000 rpm and 3, 6, 9, and 12" vacuum to look at the effect of varying engine load. The percentage torque increase as a result of firing two plugs per cylinder instead of one is tabulated in Table 5-6.

Table 5-6 - Increase in Torque of Dual Ignition Case Compared to Single Ignition Case

rpm	Man. Vacuum	Avg. Torque (ft-lb) Single	Avg. Torque (ft-lb) Dual	Avg. % Increase
1500	10"	138	148.5	7.6
2000	10"	147	151	2.8
2500	10"	146	151	3.4
3000	10"	137.5	142.5	3.7
2000	3"	246	260	1.6
2000	6"	190	195	2.6
2000	9"	160	166.5	4.1
2000	12"	122.5	125	2.0

This increase ranged between 1.6 and 7.6% depending on speed and load. The highest torque increase was observed at lower engine speed (1500 rpm) while the lowest percentage increase was seen at wide open throttle.

OCTANE REQUIREMENT - Octane ratings were performed in the engine cell to determine the effect of dual spark plug ignition on engine octane requirement. These ratings were obtained during simulated 40 to 70 mph WOT accelerations on the modified 9:1 C.R. 350 CID engine. To factor out effects of deposits and ambient conditions, the rating with the standard spark plugs only was repeated several times. The data in Table 5-7 show that, if the primary plugs fire at standard timing and the secondary plugs are brought into operation, the increase in octane requirement changes in a nearly linear fashion with the firing delay between the primary and secondary plugs. For example, with the primary plugs only, the octane requirement was 86 RON at 6°BTC basic timing. When both primary and secondary plugs fire at 6°BTC basic timing the octane requirement increases to 95 RON. As a time delay is put between the firing points of the two plugs, the octane requirement drops until with a 16°CA delay in the firing of the secondary plugs the requirement is the same as if ignition is initiated only by the primary plugs.

It is clear from these results that when two flame fronts are established at opposite ends of the combustion chamber, the end gas which is now probably located near the valves, is more susceptible to autoignition despite the shorter burning time. Interestingly, the octane

Table 5-7 - Effect of Dual Ignition on Octane Requirement

Basic Timing		Octane Requirement	
Primary Plugs	Secondary Plugs	RON	MON
6°BTC	Off	86	77.0
6°BTC	6°BTC	95	84.1
6°BTC	12°BTC	97	86.2
6°BTC	1°BTC	93	83.0
6°BTC	Off	87	78.3
1°BTC	1°BTC	89.8	80.8
1°BTC	-	82	73.2
6°BTC	10°ATC	87	78.3
6°BTC	Off	87	78.3
6°BTC	24°ATC	87	78.3
Off	6°BTC	91	81.6
6°BTC	Off	87.9	78.9
6°BTC	4°ATC	91	81.6
6°BTC	20°BTC	∿102	∿90.8

requirement with ignition in the squish area only is about three numbers higher than with ignition in the standard location. This is further evidence that when the end gas is in the squish area, it is cooler than when it is in the open part of the combustion chamber and therefore less likely to detonate. If it is true that the efficacy of the squish area is due more to its capability for cooling the end gas rather than generating turbulence, it would explain why in our tests on the effect of increasing squish area no octane benefit was observed. The increased squish between the standard and the high compression heads was not likely to increase heat loss from the end gas. The result also suggests that octane benefits might be achieved by increasing the heat transfer rate from the squish zone possibly by increasing the flow of cooling fluid in that area.

These results indicate that when the only change that is made is that of switching on the secondary plugs, the engine speed, power output, and octane requirement increase.

COMPARISON OF SINGLE AND DUAL IGNITION AT EQUAL POWER

Spark Retard - In order to properly evaluate single and dual plug ignition, it is necessary to compare these cases at the same engine power output. Since a greater amount of torque is generated by dual ignition, the engine operating conditions must be changed to lower the power output when both plugs are on. One way of achieving this is by retarding the spark timing on both distributors. The amount of torque increase and of spark retard necessary to compensate for this varies somewhat with engine speed and load as shown in Table 5-8.

Table 5-8 - Amount of Spark Retard Necessary to Equalize Torque

Engine rpm	Manifold Vacuum	% Torque Increase with Dual Plugs	Spark Retard to Equalize Torque
1500	10"	7.6	7°
2000	10"	2.8	7°
2500	10"	3.4	10°
3000	10"	3.7	9°
2000	3"	1.6	1.5°
2000	6"	2.6	4.5°
2000	9"	4.1	5°
2000	12"	2.0	8°

This makes it impossible to compare single and dual ignition at equal power on acceleration because the torque cannot be equalized at all speeds. Even if the amount of spark retard necessary to equalize power in the dual ignition case was independent of engine speed, the fact that the two distributors did not have the same centrifugal advance curve make accelerations difficult to interpret. The distributors, when new, both gave the same centrifugal advance curves equivalent to the present primary curve (see Figure 5-5). The secondary distributor centrifugal curve became advanced over the primaries at engine speeds above 1800 rpm. This is probably due to a change in spring tension or wear. Thus, the evaluation of dual ignition at equal power to the single ignition case was done at steady state to make the results interpretable.

In this phase of the work, the increased torque due to dual ignition was compensated for by retarding both distributors to produce a torque equal to the case of single ignition. When the secondary plugs are first turned on, a much higher NO_x output (along with higher power) is produced. However, when the spark timing is retarded to the point where the torque is equal to the single ignition case, usually a lower NO_x emissions level is observed as shown in Table 5-9.

Table 5-9 - Amount of Spark Retard of Dual Distributors Necessary to Make Torque Equal to Single Ignition Case, Associated % NO_x Decrease from Single Ignition Case, and Δ Octane Requirement

	Relative to Single Ignition Case		
rpm-Vacuum	° Retard	% NO_x Decrease	Δ OR
1500-10"	7*	15*	+2
2000-10"	7**	15**	+4
2500-10"	11*	40*	+1
3000-10"	9*	18*	-1
2000-3"	1.5	0	>+1
2000-6"	4.5	-18.5	+3
2000-9"	5	2.7	+2
2000-12"	8	7.0	+4

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*Average of two tests.
**Three determinations.

The percentage NO_x decrease at part throttle (10" vacuum) ranged between 15 and 40%. At 2000 rpm and low manifold vacuums, the effect was essentially nonexistent. In one case (2000 rpm and 6" vacuum) a NO_x increase was seen. The effect of dual ignition on hydrocarbon and CO emissions was small.

In almost all instances, the octane requirement was higher for dual plug ignition than for single ignition. The increase ranged between 1 and 4 numbers. In one case (3000 rpm - 10" vacuum), the octane requirement went down one number, however.

A couple of acceleration runs were made for octane requirement and acceleration times using full-boiling range (CX) reference fuels as shown in Table 5-10.

FIGURE 5-5

SPARK ADVANCE CURVES FOR DUAL DISTRIBUTORS

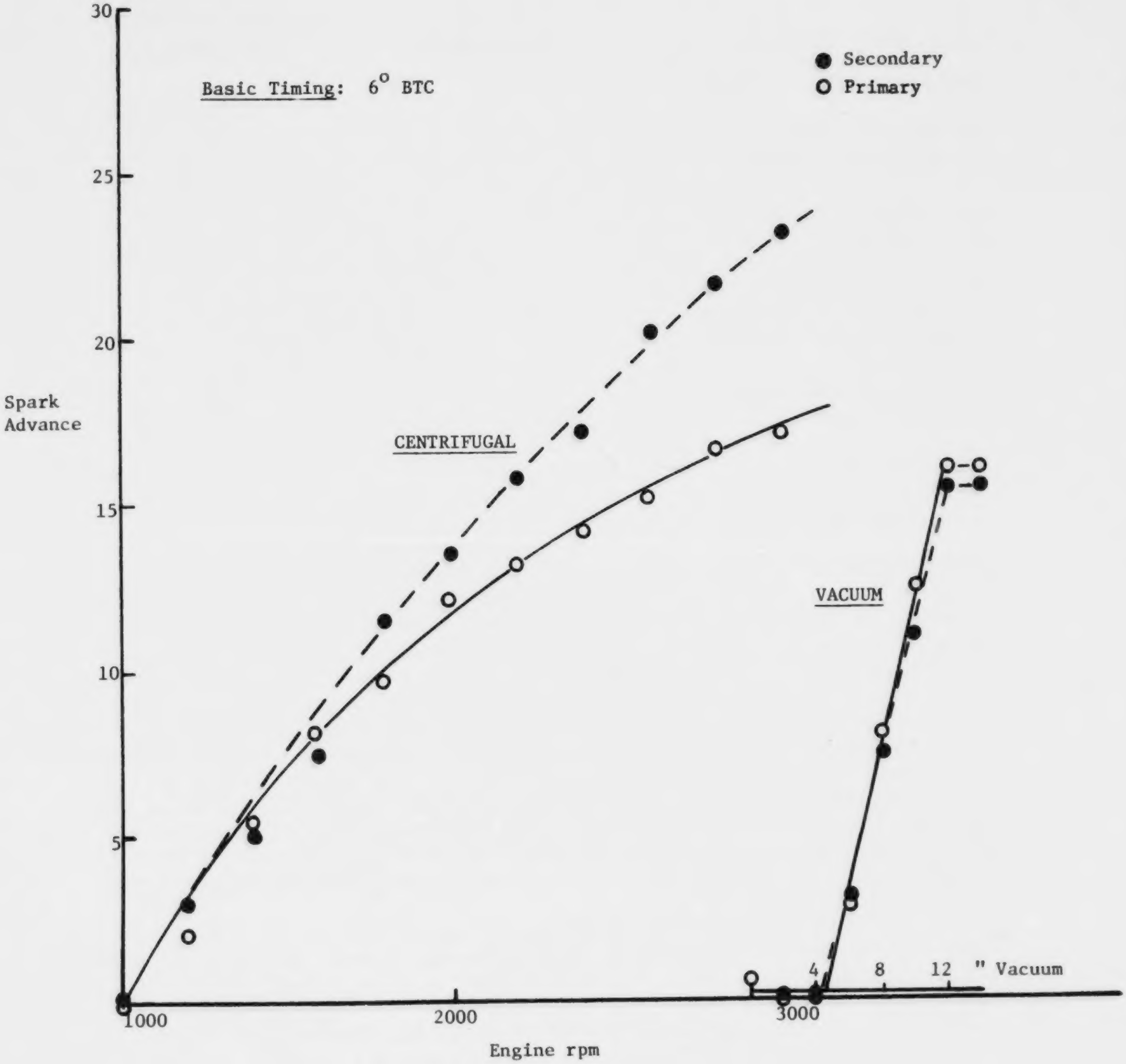


Table 5-10 - Full Throttle Acceleration Octane Ratings (CX Fuels)

Description	Octane Requirement	40-70 mph Acceleration Time (sec.)
Primaries Only - 6°BTC	89	14.7
Primaries - 6°BTC Secondaries - 6°BTC	99	14.5
Equal Power Set Up at 1500 rpm - 10" Basic Timing: Primaries - 1.5°ATC Secondaries - 1.5°ATC	94	15.5
Equal Power Set Up at 2500 rpm - 10" Basic Timing: Primaries - 6°ATC Secondaries - 12°ATC	84	19.1

These runs are the equivalent of 40 to 70 mph full throttle, road load, accelerations. In the first set, the single ignition case can be compared to the dual ignition one with both distributors set at standard basic timing. Here, the power is higher with both plugs on giving rise to a 10 unit higher octane requirement. In the next case, the dual ignition case was set up such that power equal to the single ignition case was obtained at 1500 rpm - 10" manifold vacuum. The power is about equal early in the acceleration but because of the advanced secondary distributor curve, more power is produced at high speed. The result is a 5 unit higher octane requirement for the dual ignition case. In the final comparison, the dual distributors were set up for equal power at 2500 rpm - 10" vacuum. The timing is so retarded, however, at low speed that a 30% longer acceleration time and 5 unit lower octane requirement result.

Using spark retard to lower the torque in the dual ignition case to the same level obtained for single spark plug ignition has shown the following:

(1) Spark retard reduced the high dual ignition engine's octane requirement. However, the reduction was not large enough to lower the octane requirement to the base single ignition level and thus the requirement was elevated from 0 to 4 numbers above the base case.

(2) NO_x emissions were reduced on the average of 22% at part throttle with no effect observed at 3 and 6" manifold vacuums.

(3) CO and HC emissions were only slightly affected.

These results suggest that the dual ignition engine has a higher octane requirement which cannot easily be overcome by conventional means. This may be due, in part, to the location of the secondary spark plug. That is, by generating two flame fronts, the end gas may be raised to higher temperatures and pressures than normal, resulting in higher octane requirement. It is possible that with the optimal secondary plug location, different results would be obtained. However, this was beyond the scope of this work.

Throttle Reduction - Steady state fuel consumption was measured with single and dual ignition at constant throttle, with no differences, as would be expected. In other tests, the throttle was adjusted to reduce the torque in the dual ignition case to the base single ignition level. In this comparison at equal torque, the dual ignition runs used 1.6 to 3.9% less fuel depending on speed and load as shown in Table 5-11.

Table 5-11 - Reduction of Fuel Consumption by Reducing Throttle to Achieve Equal Torque

Engine rpm	Manifold Vacuum	% Reduction in Fuel Consumption
1500	10"	3.9
2000	3"	3.9
2500	10"	1.6

EGR Flow - A similar attempt was made to compare single and dual ignition at equivalent power by increasing EGR flow in the dual ignition case. The comparison between dual and single ignition was made at constant throttle position. To accomplish this, the engine could not be shut down in between changes in EGR flow, since the throttle might not return to exactly the same position. Thus, the standard GM ported EGR valve was used to run a series of base case EGR flows given in Table 5-12.

Table 5-12 - Measurement of % EGR Flow for Standard GM Recycle Valve on 350 Chevrolet Engine in Engine Cell

Engine rpm	Manifold Vacuum	% EGR
1500	10"	7.2
2000	10"	6.0
2500	10"	5.3
2000	6"	4.7
2000	3"	<0.5

The valve was then replaced permanently with the GM proportional recycle valve and the new "base case" flow set to correspond to that of the stock valve. The second set of plugs was then turned on to measure the increase in torque from dual ignition. EGR was then added at constant throttle position, allowing the manifold vacuum to decrease, to lower the torque to approximately the base case level. The comparison between single ignition with standard EGR rates and dual ignition with increased EGR was made at several different engine speeds and vacuums shown in Table 5-13. The detailed individual test results are given in Appendix E. In all cases, the octane requirement increases substantially (from 3 to 8 units).

The emissions results showed that NO_x emissions decreased by typically 20% while the hydrocarbon emissions levels increased by 25% or more. The fact that NO_x emissions are reduced by EGR but the octane requirement remains high suggests that the high octane requirement generated in the dual ignition case is not effectively compensated for by increasing the EGR flow. This was also noted in the case of spark retard. However, EGR flow increase seems to be less effective than spark retard in lowering the engine's octane requirement. Fuel consumption was observed to decrease from 0.6% to 5.3% depending on speed or load.

In some of the tests shown in Table 5-13, an additional case was run where the EGR flow was increased even further and the throttle adjusted to keep equal torque. In the case run at 2000 rpm and 6.0" manifold vacuum, the octane requirement was just lowered to the base level using this further EGR increase. However, CO increased dramatically and fuel consumption also increased. This, of course, was due to the fact that we had to go deeper into the throttle to get equal torque with the additional EGR. At 2000 rpm and 3" manifold vacuum, where the octane requirement is the highest, this additional EGR increase coupled with more throttle may have increased the octane requirement due to the larger throttle opening.

In conclusion, the dual ignition work has shown a strong tendency toward higher octane requirements. With few exceptions, this tendency cannot be overcome by retarding spark timing or doubling the EGR flow. However, these procedures do give much lower NO_x emissions when compared at equivalent torque. It is possible that a dual ignition system which had the spark plugs positioned differently might show an octane requirement benefit. However, the spark plug design which we have studied very clearly has a tendencey toward higher octane requirement.

Table 5-13 - Effect of Increased EGR Flow at Constant Throttle Position on Octane Requirement, Emissions and Fuel Consumption of Dual Ignition Engine

Engine rpm	Manifold Vacuum (in. Hg)	Total % EGR	Δ Manifold Vacuum* (in. Hg)	Δ RON Requirement	% Change			% Change in Fuel Consumption
					CO	HC	NO_x	
1500	10	13.5	-0.7	+3	0	+26	-27	-0.6
2000†	10	12.5	-1.0	+7	0	+14	-25	-3.3
2500	10	10.2	-0.7	+7	0	+38	-4	-4.5
2000†	6	8.1	-0.5	+5	+13	+40	-20	-1.7
2000	3	6.1	-0.3	+8	-	+2	Instrument Malfunction	-5.3
EGR Further Increased and Throttle Adjusted to Equalize Torque								
2000	10	16.1	-2.2	+4	0	+3	-53	-2.0
2000	6	12.6	-1.5	0	+109	+24	-45	+2.5
2000	3	8.1	-1.4	>9	-	+7.7	Instrument Malfunction	-6.2

---

*Change in manifold vacuum when EGR flow is increased.

†Average of two cases.

5.3 ALUMINUM HEADS

A comparison was made between aluminum and cast iron cylinder heads to determine if the better heat transfer properties of aluminum could be translated into an octane requirement benefit. The intention was to obtain a direct comparison of cast iron versus aluminum heads on a 350 C.I.D. Chevrolet engine.

The aluminum heads were obtained through EPA from Speedmasters, a Chicago speed shop. These heads were of identical volume to the 1969 cast iron heads. A 9:1 C.R. was achieved for both the aluminum and cast iron heads by coupling them with the standard 1975 350 CID engine block (see Figure 5-6). Photographs of these heads are shown in Figure 5-7 for comparison.

Octane requirements were measured on three rating fuel series during simulated 40 to 70 mph WOT accelerations in high gear. The requirement was measured initially with a clean engine and again after 150 hours of deposit accumulation on unleaded fuel at 50 mph road load. The data are summarized in Table 5-14. For the three fuel series, the requirement increased by only one unit after 150 hour deposit equilibration for the cast iron head. This increase is quite low and may be due to the steady speed used in testing. The cast iron head data formed the base case with which the aluminum head data was compared.

Table 5-14 Comparison of Octane Requirement of Cast Iron Versus Aluminum Heads

Fuel Series	Cast Iron 0 Hrs	 150 Hrs	Aluminum 0 Hrs.
CX	93	94	88
C	91	92	87
P	90	91	87

In the assembly of the aluminum head engine, it was noted that several major differences existed between the aluminum and cast iron heads. The intake ports were considerably larger and there was an increased intake breathing area in the aluminum heads. Because of the larger ports, the head could not be sealed properly to the intake manifold. After an extensive effort to locate a different manifold, it was decided to "Heliarc" enough aluminum into the head ports so that the manifold could be sealed. When the engine was assembled, an additional problem was encountered. In the Standard 350 engine, the valve to valve center measurement is 1 7/8" compared to 2" in the aluminum heads. Thus, one of the rocker arms of each cylinder was slightly cocked. A push rod guide plate supplied with these heads was used.

The engine was octane rated at 0 hrs. with the results shown in Table 5-14. After 3 hours of running, the test was discontinued because of a bent push rod due to the valve train assembly misalignment mentioned previously. The comparison of initial ratings show that the aluminum head engine gave a 3 to 5 number lower octane requirement than the cast iron engine. Due to the differences in the construction of the heads, it is not possible to attribute this lower requirement exclusively to the aluminum. Although the compression ratios were identical, the aluminum head used different valves and had a different intake port design. The effects of these variables on octane requirement were not determined. In addition, a comparison at deposit equilibrium could not be obtained. It is possible that any benefit obtained by the use of aluminum might be negated by the extremely good insulating properties of combustion chamber deposits after equilibration. Therefore, the results are really inconclusive.

FIGURE 5-6

350 CID ENGINE ASSEMBLED WITH ALUMINUM HEADS

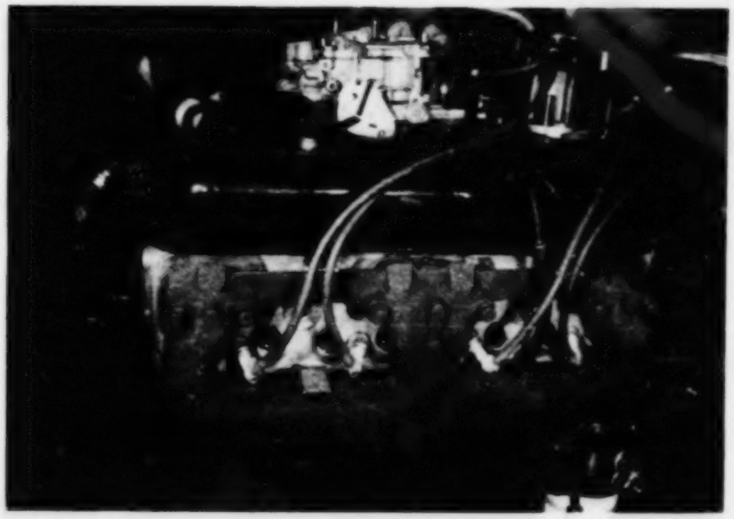
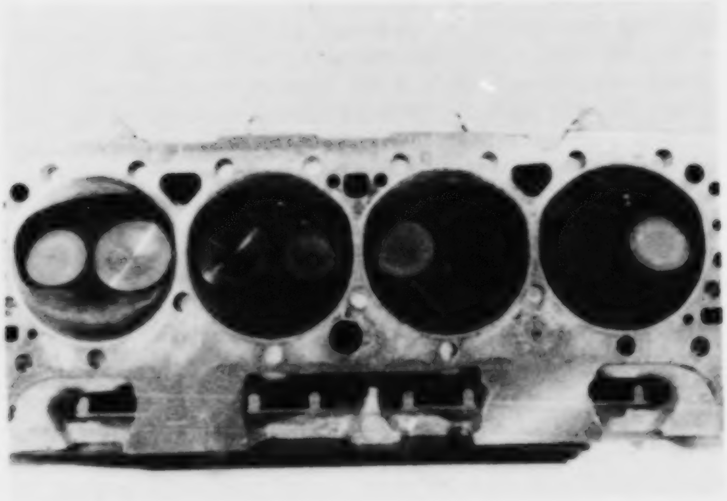
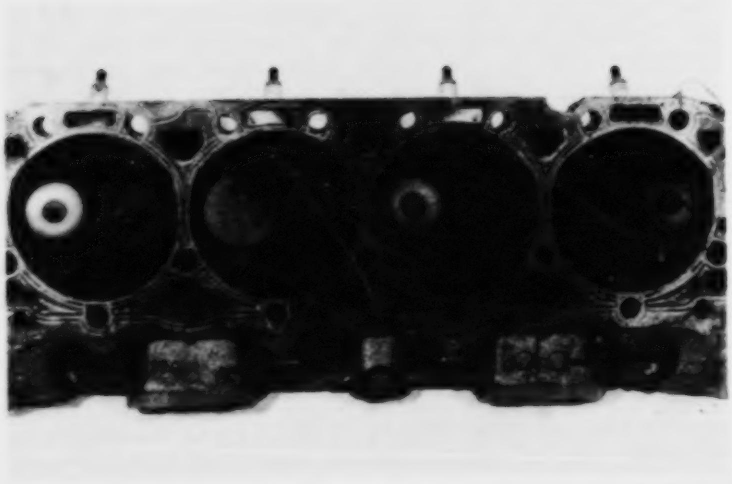


FIGURE 5-7

ALUMINUM AND CAST IRON HEADS



Aluminum
Heads



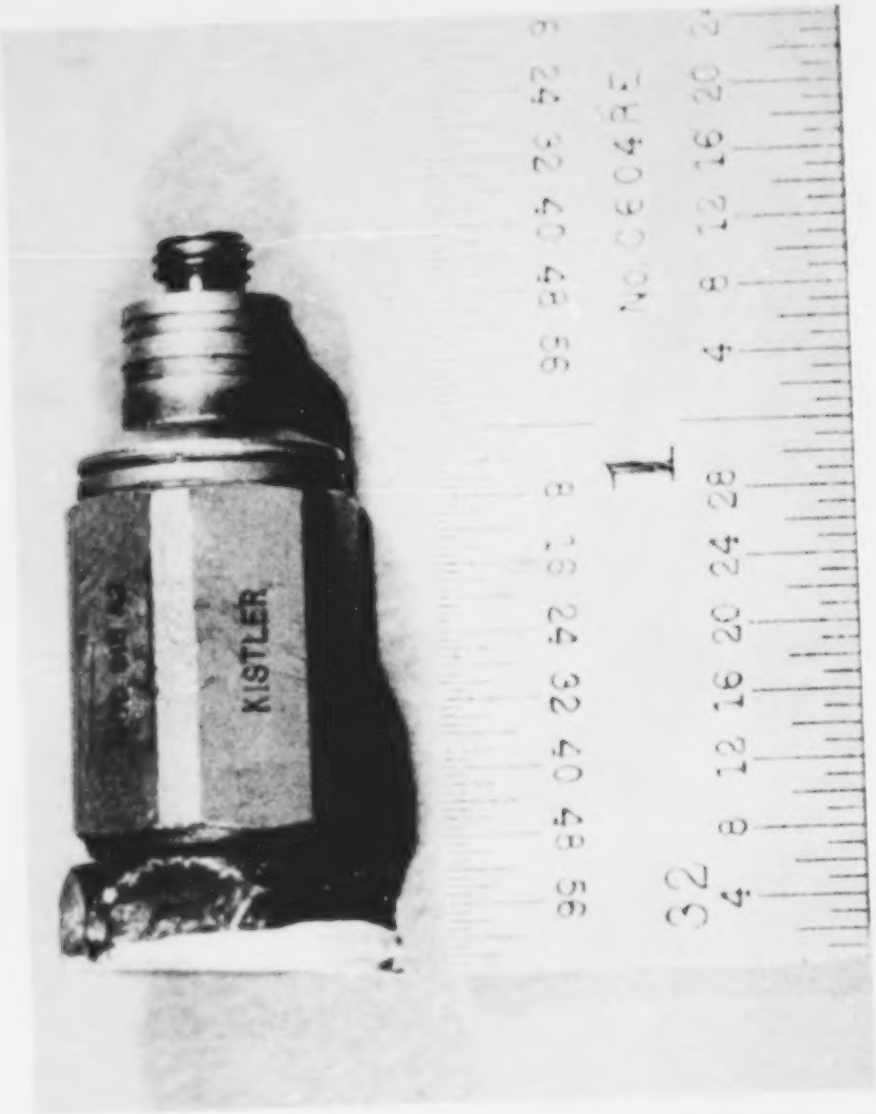
1969 Cast
Iron Heads

5.4 KNOCK SENSOR-ACTUATED SPARK RETARD

The final approach used to try and lower the engine's octane requirement was the use of controlled spark retard. The concept was to use spark retard only when detonation occurred and then only for the duration that was necessary to prevent additional detonation. In this manner, the engine would only be retarded for a small fraction of the typical driving regime and thus fuel economy and exhaust emissions would not appreciably be affected. This approach proved to be the best and was incorporated into the vehicle modifications to lower the 9:1 C.R. vehicle's octane requirement.

FREQUENCY ANALYSIS - In order to ascertain the feasibility of using a knock sensor-actuated spark retard system, accelerometers were mounted on a standard 350 CID engine with an 8:1 C.R. in an engine cell. Quartz piezoelectric transducers (accelerometers) were used to pick up vibrations of the engine and convert them to an electronic signal. The accelerometer, shown in Figure 5-8 with the attached mounting pedestal, is epoxied onto the metal surface as shown in Figure 5-9. Accelerometers were mounted in various locations on the cylinder heads and on the intake manifold as shown in Figure 5-10. Five of the accelerometers were mounted perpendicular to the axis of the crankshaft while the one located at the rear of the engine was affixed with its axis parallel to that of the crankshaft. Tape recordings of the accelerometer output were made under steady state and accelerating conditions with and without detonation. Three types of tests were run. Fuel change tests were run at steady state with the fuel changed from no knock to a low octane fuel to obtain different knock intensities. The steady state tests were run on the same fuel in each run. Acceleration tests were run from 1700 to 3000 rpm (40 to 70 mph) at wide open throttle with fuels of different octane quality. The accelerometer signals from these tests were analyzed to determine the frequency of knock in the 350 CID engine. Comparison of the signals from the accelerometers showed that the accelerometer with its axis parallel to the crankshaft and located at the rear face of the engine detected detonation most consistently. Representative traces of the frequency spectrum obtained from the accelerometer signal are given in Figure 5-11A for a fuel without detonation and in Figure 5-11B for a fuel with very light knock intensity. A complete set of these frequency analyses is given in Appendix A. These plots represent the signal amplitude expressed as g-force vs. frequency obtained during a wide open throttle 40-70 mph acceleration in top gear. In comparing the two plots in Figure 5-11, it can be seen that when detonation occurs, the intensity of the signal at approximately 5.2 kHz and at 9.0 kHz is increased. The 5.2 kHz peak was used to design the filter for the spark control system. The 9.0 kHz peak was not tried but might also be usable. The engine from the vehicle was tested with the results being virtually identical. For this engine, the accelerometers were located on the heads as shown in Figure 5-12. This vehicle engine was then modified by the use of 1969 350 CID heads to raise the compression ratio to 9:1. Analyses again indicated that the accelerometers located at the rear of the engine with their axes parallel to the crankshaft gave the best results and that the frequency of detonation was about the same. This latter engine was reinstalled in the vehicle. The fact that the two engines tested gave identical results suggests that within an engine type, the knock frequency is about the same.

FIGURE 5-8 Kistler Piezoelectric Accelerometer With Mounting Pedestal



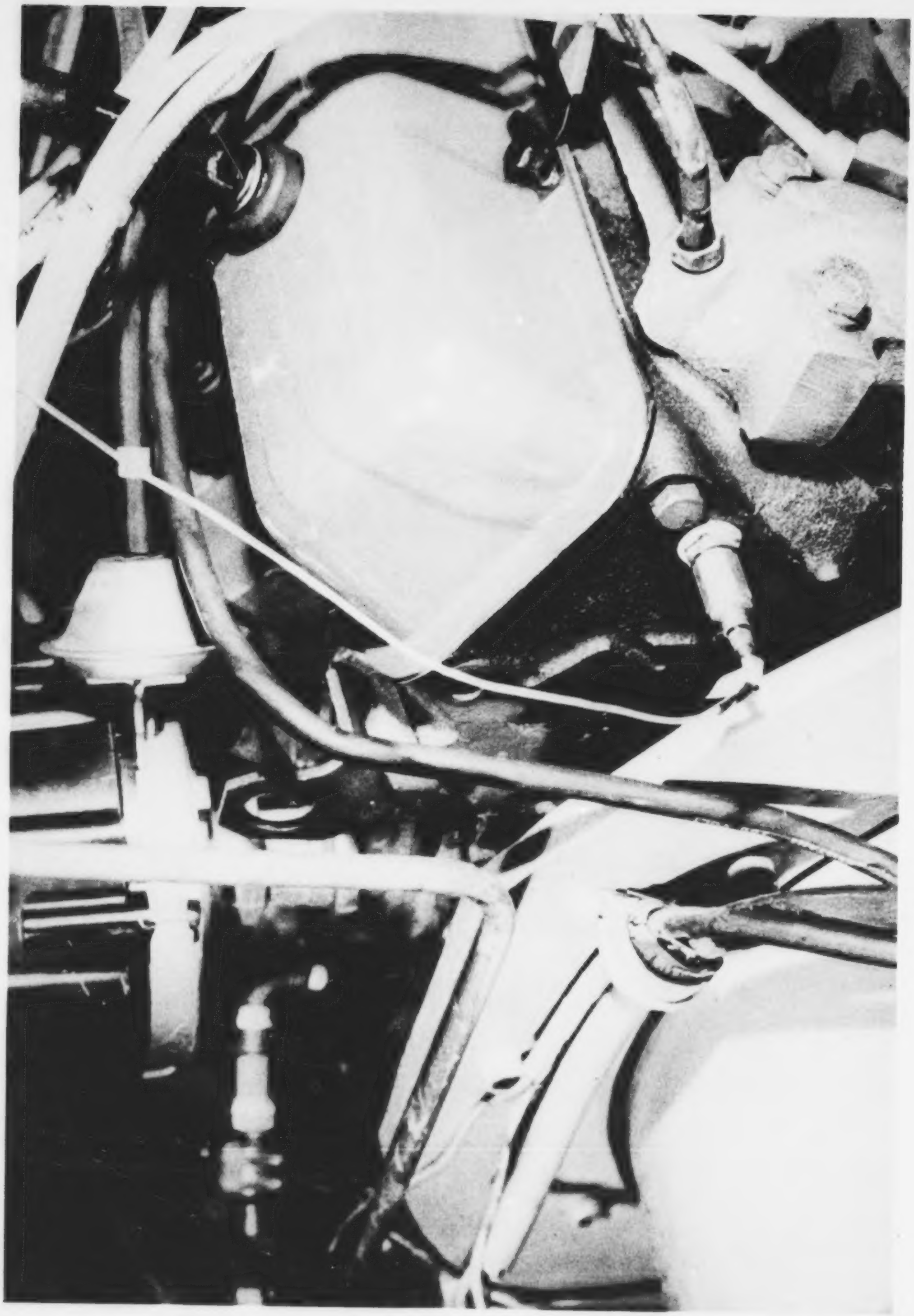


FIGURE 5-9 - Accelerometer Attached to Right Rear Cylinder Head of 350 CID Engine with Axis Parallel to Engine Crankshaft

FIGURE 5-10 - Location of Accelerometers On Spare 350 CID Engine As Tested For Knock Frequency Analysis

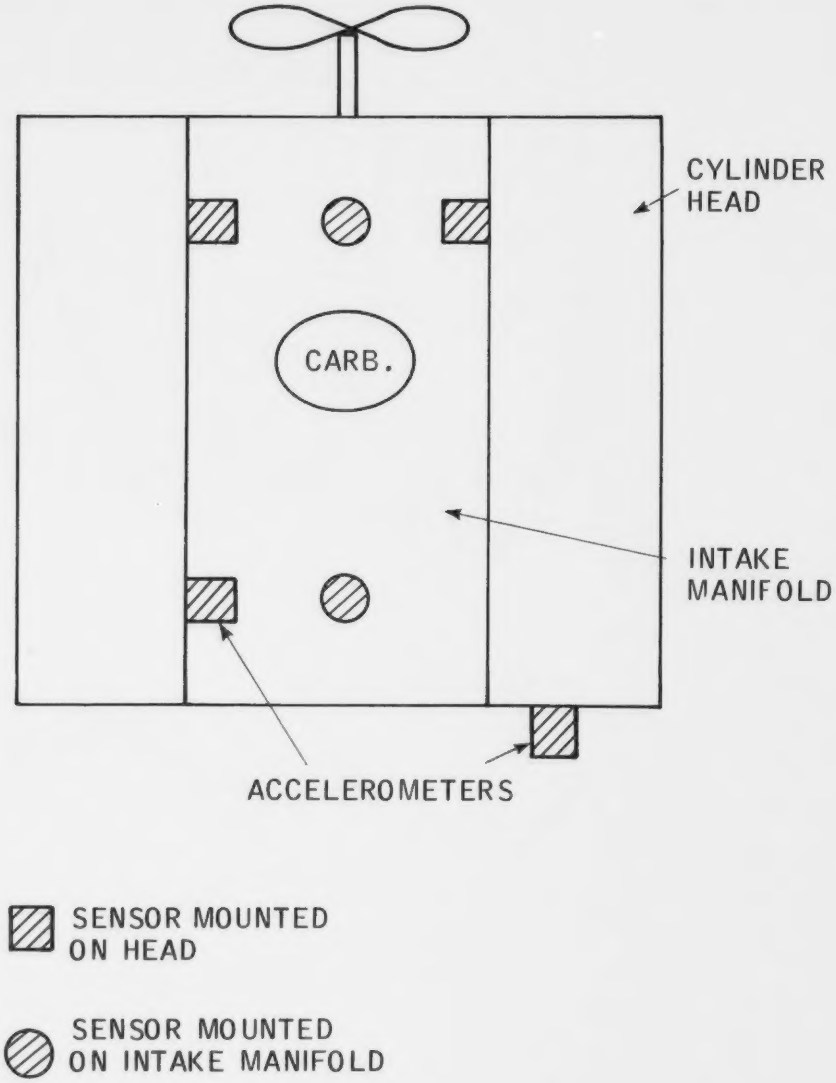

CYLINDER HEAD
CARB.
INTAKE MANIFOLD
ACCELEROMETERS
SENSOR MOUNTED ON HEAD
SENSOR MOUNTED ON INTAKE MANIFOLD

FIGURE 5-11 Frequency Analysis Of Accelerometer Signal
A) In The Absence of Detonation and
B) With Very Light Knock

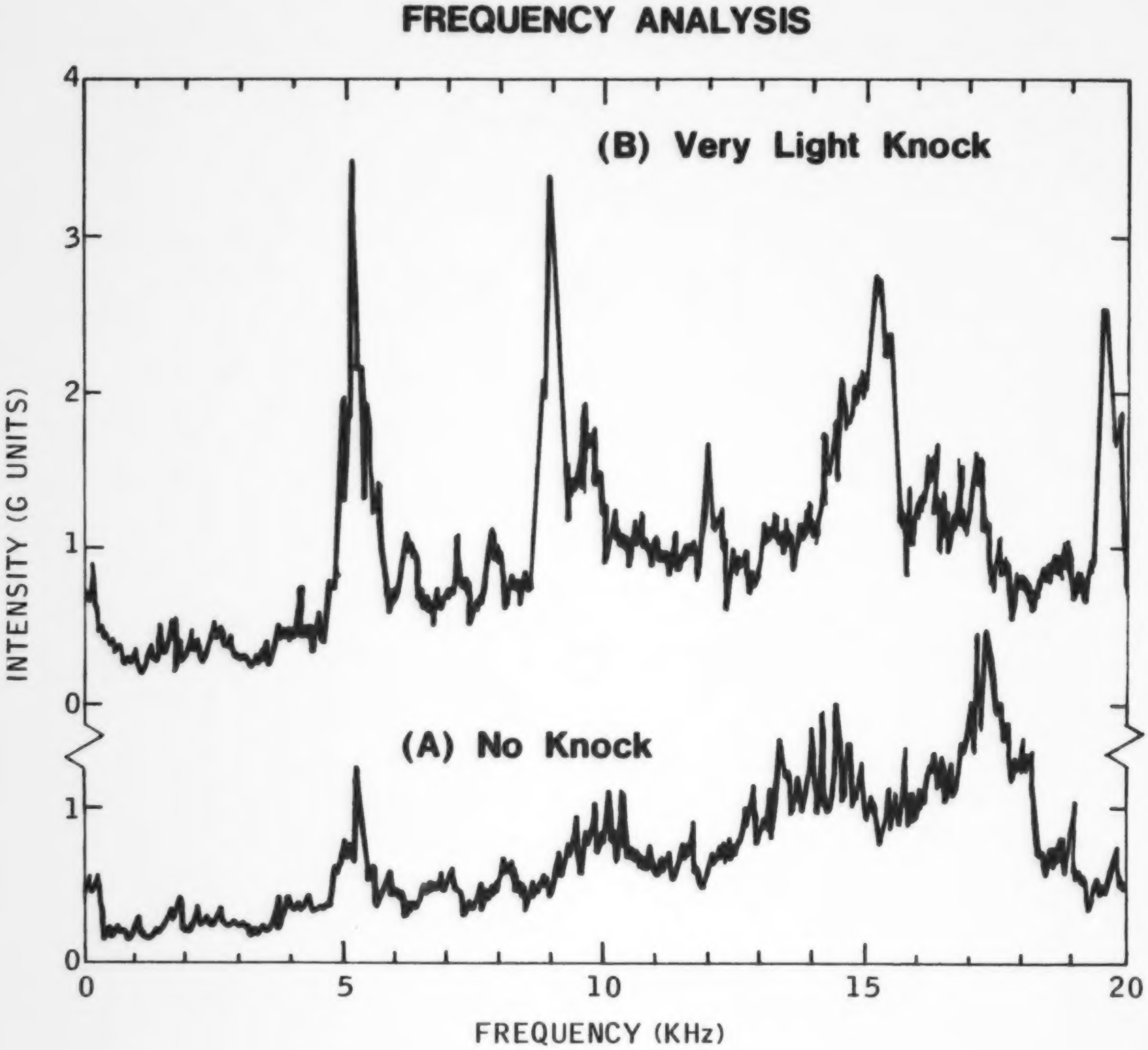
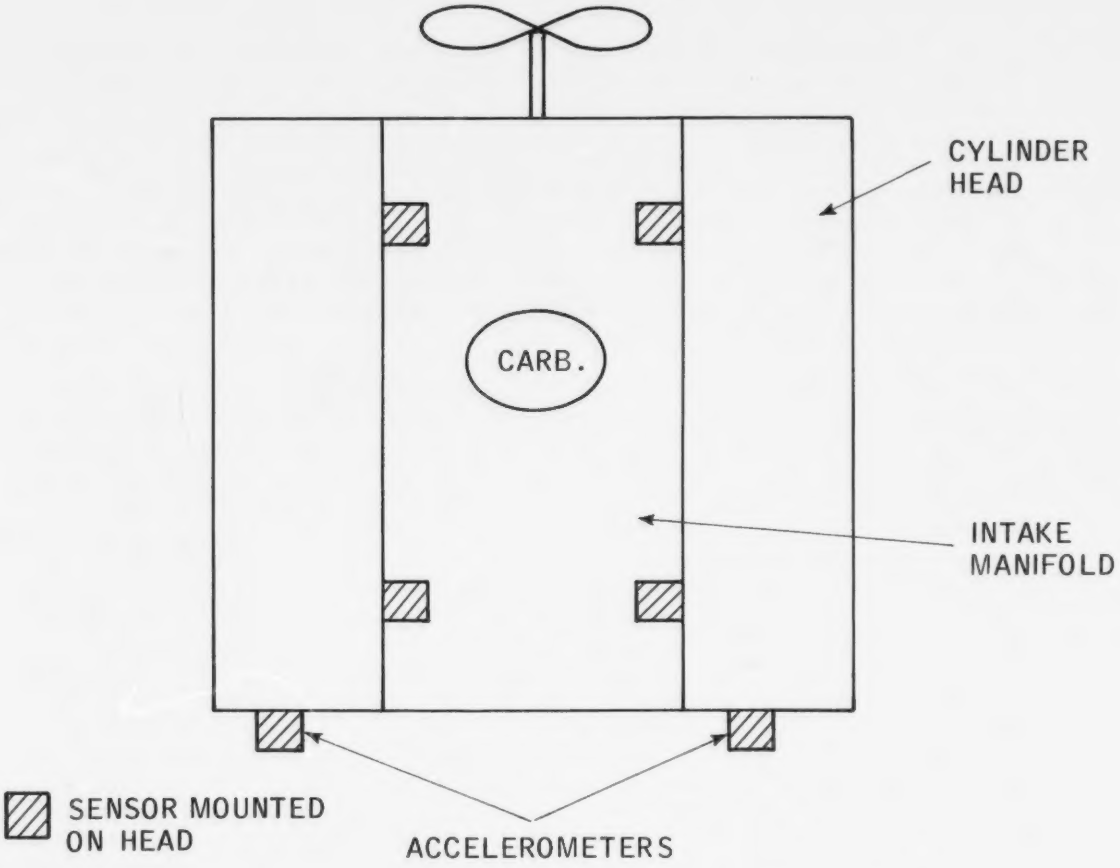


FIGURE 5-12

LOCATION OF ACCELEROMETERS

ENGINE IN VEHICLE


CYLINDER HEAD
CARB.
INTAKE MANIFOLD
ACCELEROMETERS
▨ SENSOR MOUNTED ON HEAD

CHARACTERISTICS OF ACCELEROMETER SIGNAL - A recording of engine noise as detected by the accelerometer is shown in Figure 5-13. Here, contiguous segments of signal amplitude are shown vs. time for approximately three crankshaft revolutions. The data were obtained during a 40-70 mph WOT acceleration of the engine in third gear. The engine speed is approximately 2200 rpm, and the approximate engine crank angle degrees are given for orientation. Two knock pulses are marked in the figure. They occur approximately 720° apart, indicating that they are from the same cylinder. One knock pulse lasts for 2.5 msec and the other 4.6 msec, which is fairly typical of others examined. The other signals seen are valve noises which are of a much shorter duration than detonation.

ELECTRONICS ASSOCIATED WITH KNOCK DETECTOR AND SPARK CONTROL SYSTEM - There are two characteristic features of the accelerometer signal from the 350 CID engine which can be used to identify detonation. Firstly, spectrum analyses of the accelerometer signal show that most detonation is characterized by vibration in the range of 5-5.5 kHz. Secondly, oscilloscope recordings indicate that most knock pulses last for a period of about three milliseconds or longer. The electronics module has been optimized to recognize both the narrow frequency range and longer duration of the knock signature and thus differentiates between detonation and other engine noises. A special automatic gain control circuit holds the engine background noise constant.

A block diagram of the knock sensor-spark retard system used to control the level and quantity of detonation is shown in Figure 5-14. The accelerometer signal (see Fig. 5-15) is amplified, passed through a 5.35 kHz filter with a 580 Hz bandwidth, is rectified, integrated, and compared with a preset threshold level, (see Fig. 5-16) resulting in a detected knock pulse. This threshold level is set so that the system will respond to a specified level of audible knock. When a knock signal is detected, the digital controller produces a DC control voltage. This DC voltage is the input to the spark delay control. The degrees of spark retard from the production spark curve are proportional to this DC voltage level generated by the digital controller. This controller also receives the distributor signal, which acts as the reference clock for the system, and delays it when knock is sensed (i.e., spark retard is implemented electronically). The spark retard is accomplished in a stepwise manner in response to each knock pulse sensed. The retard is maintained for a programmed number of engine revolutions, after the last detected knock (delay 1). The spark timing is then advanced in steps back to the standard spark schedule with a specified number of revolutions (delay 2) between steps. Should a knock signal be detected at any point in the sequence, the spark timing is immediately retarded.

The detailed control schematic is shown in Figure 5-17. The circuit to the right representing the filter circuit and the digital control leading to the 0-11 volt control voltage was designed at Exxon. The circuit operating off this control voltage is a Delco design.

FIGURE 5-13 Accelerometer Signal Vs. Engine Crank Angle Degrees Showing Duration of Engine Noises

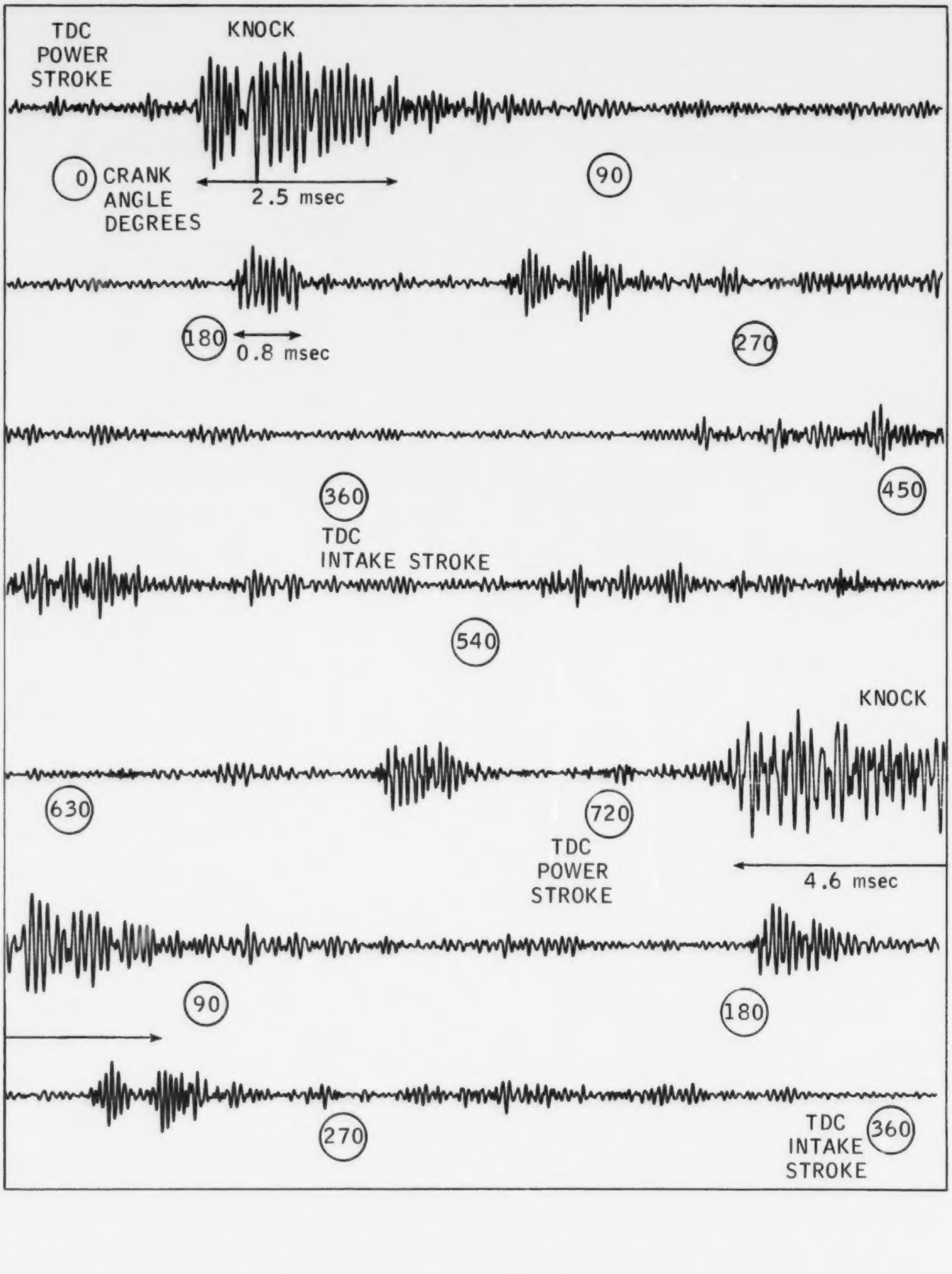


FIGURE 5-14

BLOCK DIAGRAM OF KNOCK SENSOR ELECTRONICS

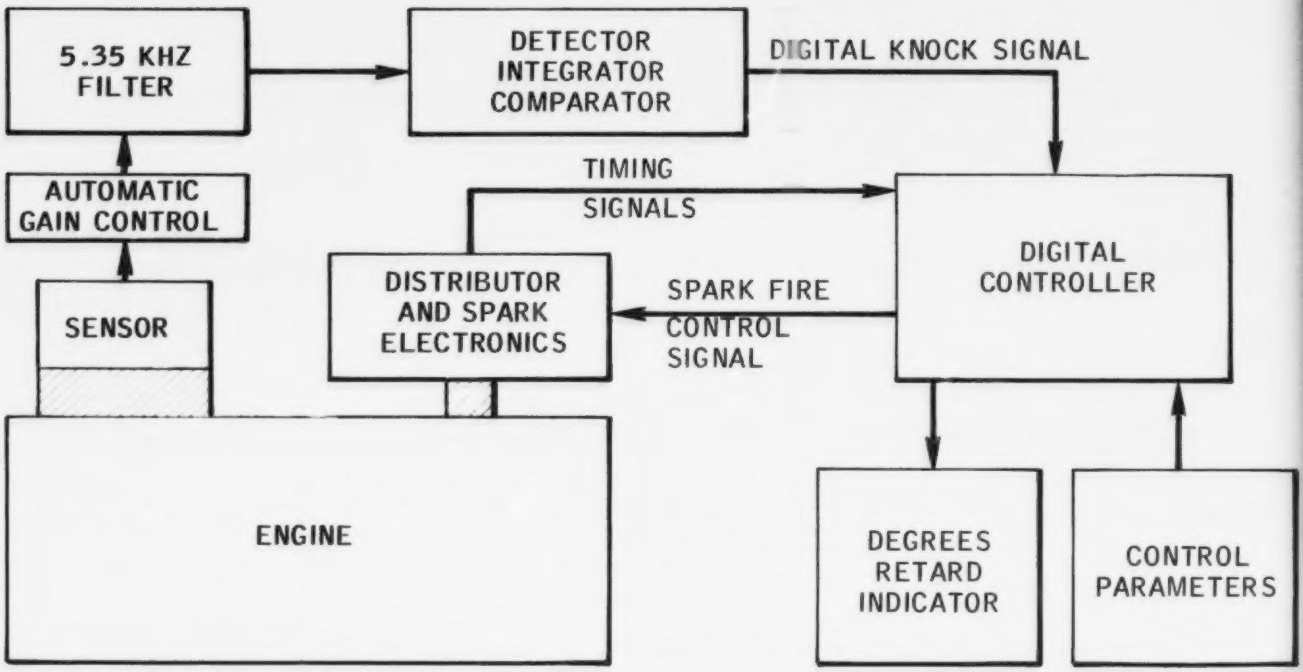

5.35 KHZ FILTER
DETECTOR INTEGRATOR COMPARATOR
DIGITAL KNOCK SIGNAL
AUTOMATIC GAIN CONTROL
TIMING SIGNALS
DIGITAL CONTROLLER
SENSOR
DISTRIBUTOR AND SPARK ELECTRONICS
SPARK FIRE CONTROL SIGNAL
ENGINE
DEGREES RETARD INDICATOR
CONTROL PARAMETERS

FIGURE 5-15

ACCELEROMETER SIGNAL WITH KNOCK PRESENT

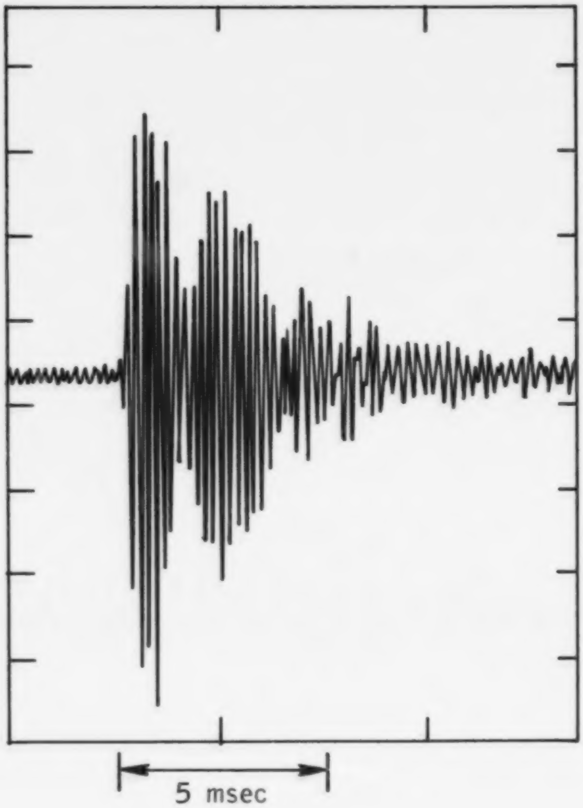


FIGURE 5-16

ACCELEROMETER OUTPUT AND PROCESSED SIGNALS

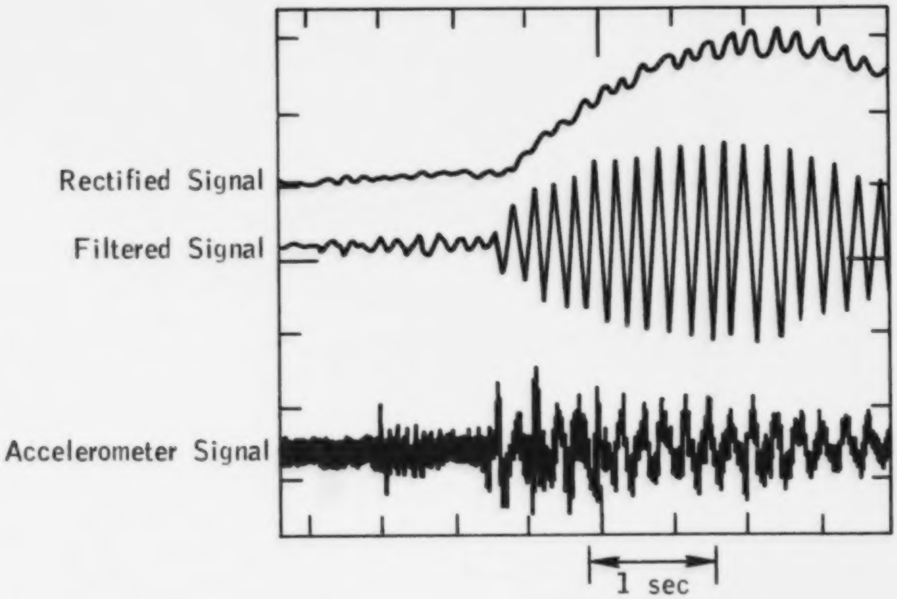
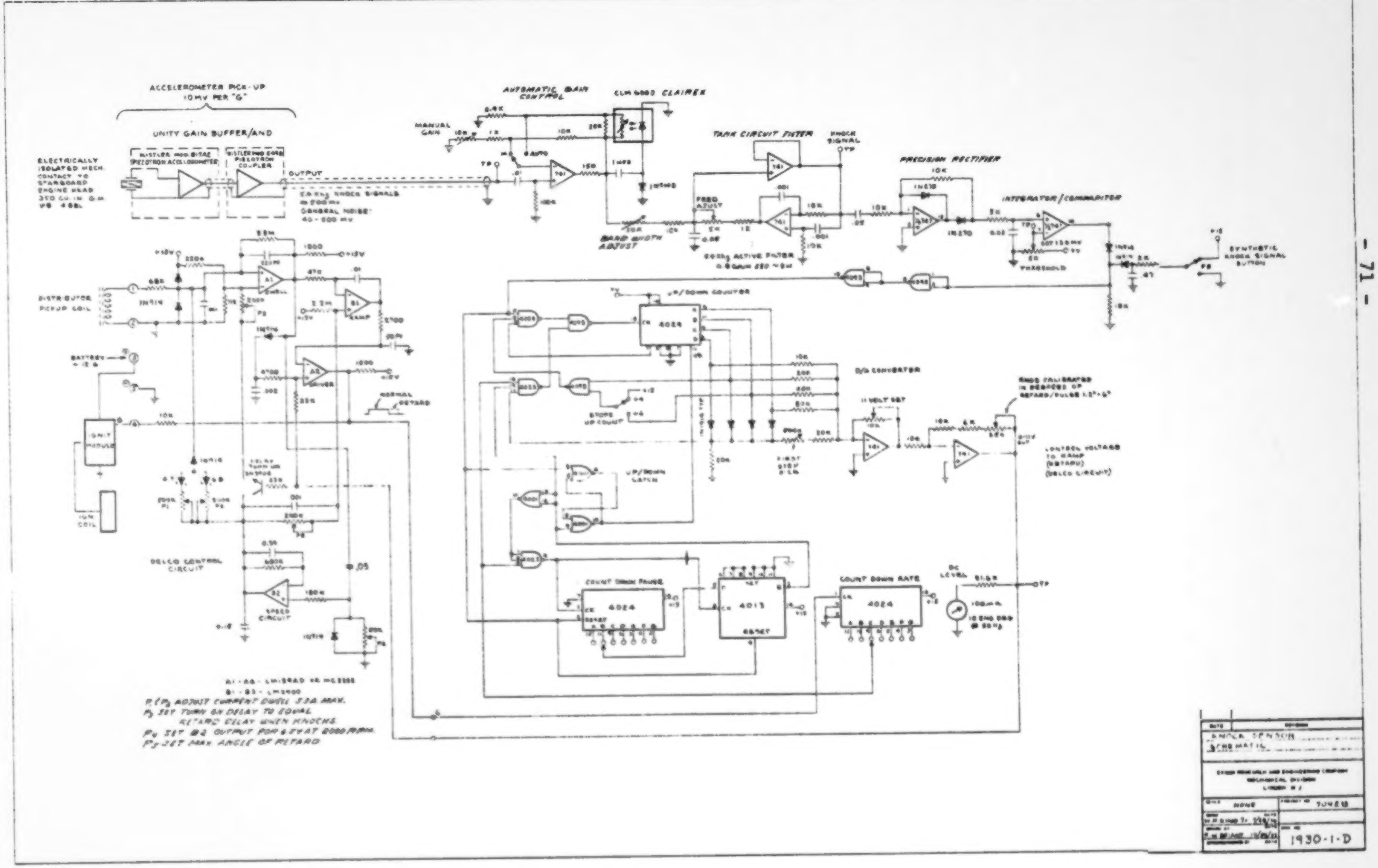


FIGURE 5-17 Detailed Circuit Diagram of Knock Sensor - Spark Retard System Electronics


ACCELEROMETER PICK-UP
10MV PER "G"
UNITY GAIN BUFFER/AND
ELECTRICALLY ISOLATED MECH. CONTACT TO STARBOARD ENGINE HEAD 350 CU. IN. G.M. V8 4BBL
OUTPUT
GENERAL NOISE 40 - 800 MV
AUTOMATIC GAIN CONTROL
MANUAL GAIN
AUTO
TP
CLM 6000 CLAIREX
BAND WIDTH ADJUST
FREQ. ADJUST
TANK CIRCUIT FILTER
KNOCK SIGNAL
ACTIVE FILTER
PRECISION RECTIFIER
INTEGRATOR/COMPARITOR
THRESHOLD
SYNTHETIC KNOCK SIGNAL BUTTON
DISTRIBUTOR PICKUP COIL
1N914
A1
B1
RAMP
A2
DRIVER
NORMAL
RETARD
BATTERY +12 V
IGNIT MODULE
ION COIL
DELCO CONTROL CIRCUIT
B2
SPEED CIRCUIT
.05
UP/DOWN COUNTER
4024
STOPS UP COUNT
D/A CONVERTER
11 VOLT SET
FIRST STEP
KNOB CALIBRATED IN DEGREES OF RETARD/PULSE
CONTROL VOLTAGE TO RAMP (RETARD) (DELCO CIRCUIT)
UP/DOWN LATCH
COUNT DOWN PAUSE
4024
4013
RESET
COUNT DOWN RATE
4024
DC LEVEL
1930-1-D

EVALUATION OF KNOCK SENSOR-ACTUATED SPARK CONTROL SYSTEM ON ENGINE - The knock sensor-actuated spark control system was first tested on an engine dynamometer stand on both the standard 8:1 C.R. 350 CID engine and on the modified 9:1 C.R. engine. Both engines were tested without significant deposit accumulation. For these tests, manual gain control was used with the sensitivity set such that the system would not retard with a no-knock fuel but would respond to T¯ knock. The filter was fixed at 5.2 kHz with a 400 Hz bandwidth. Octane requirement determinations for T¯ knock, made during simulated 40-70 mph WOT accelerations, are summarized in Table 5-15. The data indicate that controlled spark retard gives a 3-7 number octane benefit depending on how long the spark retard is held (i.e., the length of the delay time before spark advance begins). Of course, as the total amount of spark retard was increased or the time was lengthened before allowing the spark to advance, power output decreased and acceleration times increased. These data provided the basis for the subsequent attempts to utilize this technology on the vehicle.

OPTIMIZATION OF SPARK CONTROL SYSTEM - The knock sensor-actuated spark control system and the 9:1 C.R. 350 CID V-8 engine on which the system had been tested on the dynamometer stand were moved to the 1975 California vehicle. Prior to vehicle testing, system optimization was accomplished by examining the response of the control system to tape recordings of the vehicle accelerometer and distributor signals. The same sections of tape could be played back and changes made to optimize the performance of the spark control system. In this manner, several variables were examined in the process of arriving at the final settings used in the vehicle tests.

Manual vs. Automatic Gain Control - All of the work done in the engine cell was with manual gain control, with the gain being constant. During an acceleration, the accelerometer signal level increases as the engine speed increases due to the natural increase in noise level with increasing engine rpm. If the gain were set such that the controller would retard in response to knock at low engine speeds, it might also retard in the absence of knock at high engine speeds. On the other hand, if the gain is set so that retard will not occur at high speed with no knock present, the system would be less sensitive in responding to knock at lower engine speeds. For this reason, it is desirable to incorporate automatic gain control (AGC) into the system. AGC attempts to hold the output signal from the amplifier relatively constant by changing the gain automatically as the accelerometer output signal varies with engine speed. It was found, in practice, that the system with AGC responded to knock equally well at all engine speeds. Therefore, with the exception of a small amount of diagnostic work, all of the vehicle testing was done using automatic gain control.

Table 5-15 Effect of Knock Sensor-Actuated Spark Control in Engine Cell

	Research Octane Requirement			
	No Control		Controlled Spark	
	Primary Reference Fuels	High Sensitivity(CX) Full Boiling Reference Fuels*	Primary Reference Fuels	High Sensitivity (CX) Full Boiling Reference Fuels*
Standard 8:1 C.R.	81		76	
Modified 9:1 C.R.	87	85.5	84	79
Modified 9:1 C.R. (Long Delay Time) Delay-1 - 1024 engine revolutions Delay-2 - 32 engine revolutions	86		79	

* See Appendix 2.

Filter Settings - One of the most critical parts of the entire system is the filtering of the input signal. Originally, the filter was set according to the frequency analysis data obtained under knocking conditions in the engine cell. This data indicated that for the 350 CID engine the predominant knock signal was centered about 5.1-5.2 kHz and was approximately 400 to 500 Hz wide. The filter was designed to approximately match the knock signal envelope. Using tape recordings of actual vehicle accelerometer signals, the system was tested for response to knock for a range of filter center frequencies from 4.9 to 5.7 kHz. In Figure 5-18, the relative intensity of the detected knock signal is plotted against filter center frequency setting for three different detonation intensities. It was apparent from these tests that 5.35 kHz was the optimal filter center frequency. Several filter bandwidths ranging from 200 to 1400 Hz were also examined. A bandwidth of 580 Hz was chosen for the vehicle studies.

Threshold Setting - The threshold value at which a detected knock pulse is allowed to trigger the spark control system is very important in determining the overall performance of the system. The threshold can be set such that inaudible "knock" will produce spark retard. Although in this case, most of the detonation will be eliminated, even with low octane fuels, it will result in some unnecessary retard and excessively long acceleration times. The threshold was chosen such that some small amount of knock (T^- level) would be tolerated by the system, i.e., the system sometimes responds to T^- level knock and sometimes does not. Since occasional low intensity detonation is not harmful to the engine or generally perceived by the driver, such a threshold setting (i.e., lower sensitivity to detect knock) seems appropriate.

Degrees of Retard per Knock Event - In all experimentation with the spark control system on the vehicle, 10° was the maximum retard allowed. This retard is achieved in either four or six incremental steps. Most of the work was done with six steps to a total of 10° maximum retard. A refinement was made to allow the first step to be larger (usually 2.5°) than the remaining five steps.

Spark Advance Delay Times - There are two delay controls for allowing the spark timing to advance back to its normal schedule. These two controls determine the number of engine revolutions before the spark advances the first step and the number of engine revolutions between subsequent steps. The effect of these delay times on detonation is illustrated in Figures 5-19 through 5-22 where the knock signal and amount of spark retard are displayed: for Figure 5-19 - an uncontrolled case, Figure 5-20 - a short delay where the initial stepdown occurs after 16 engine revolutions followed by 2 engine revolutions between each additional step, Figure 5-21 - a medium delay whereby the initial step of spark advance occurs after 128 revolutions with each additional step every 16 revolutions, and Figure 5-22 - a long delay where the initial delay is 1,024 revolutions followed by 32 revolutions between each additional step. It can be seen that while considerable detonation is eliminated for the short delay time case, it is necessary to go to longer delay times to prevent detonation from occurring in the middle of an acceleration due to the premature advance of the spark timing. In the vehicle studies, most of the work was done with the long delays, i.e., delay 1 was 1,024 engine revolutions and delay 2 was 32 engine revolutions. Some tests were also run with delays of 128 and 32 engine revolutions respectively.

FIGURE 5-18 INTENSITY OF KNOCK SIGNAL VS. FILTER CENTER FREQUENCY FOR THREE KNOCK PULSES OF DIFFERENT INTENSITY

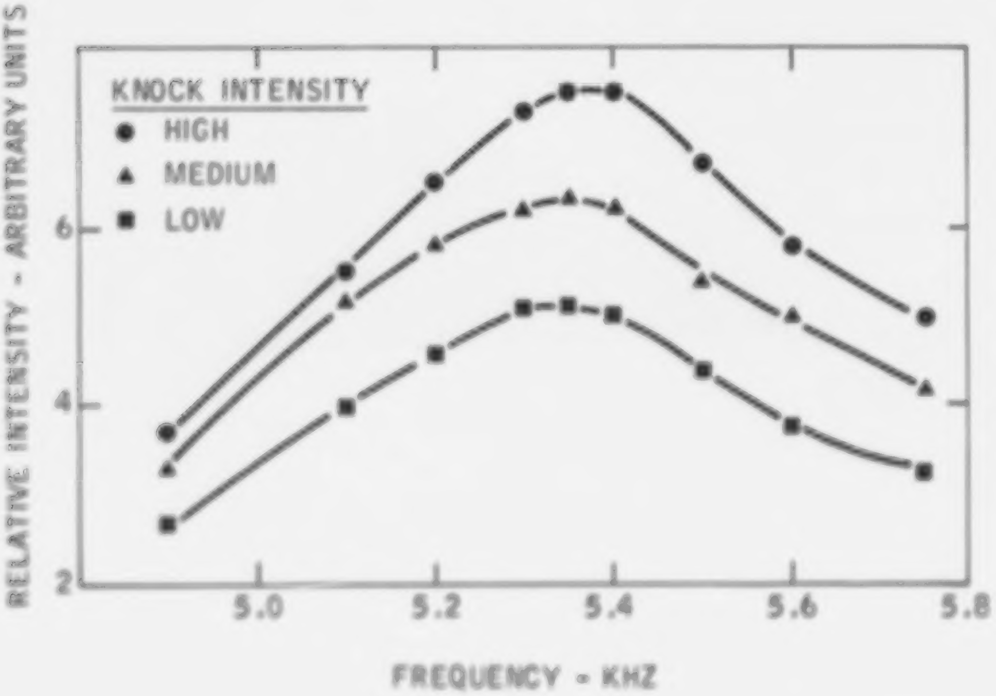


FIGURE 5-19

KNOCK SIGNAL VS. TIME DURING 40-60 MPH ACCELERATION USING KNOCKING FUEL WITH NO SPARK CONTROL

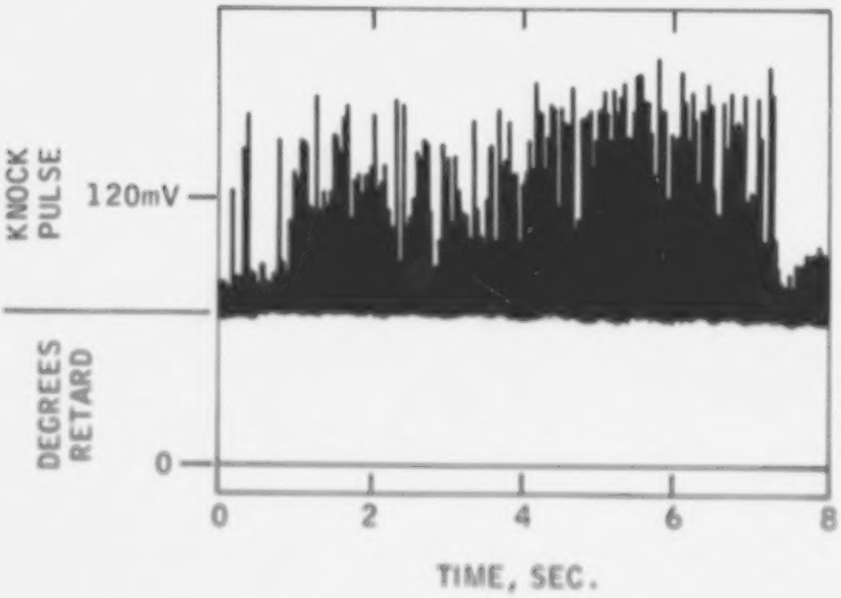


FIGURE 5-20

TOP - KNOCK SIGNAL VS. TIME DURING 40-60 MPH ACCELERATION USING KNOCKING FUEL WITH CONTROLLED SPARK TIMING

BOTTOM - SPARK RETARD WITH SHORT SPARK ADVANCE DELAY TIMES

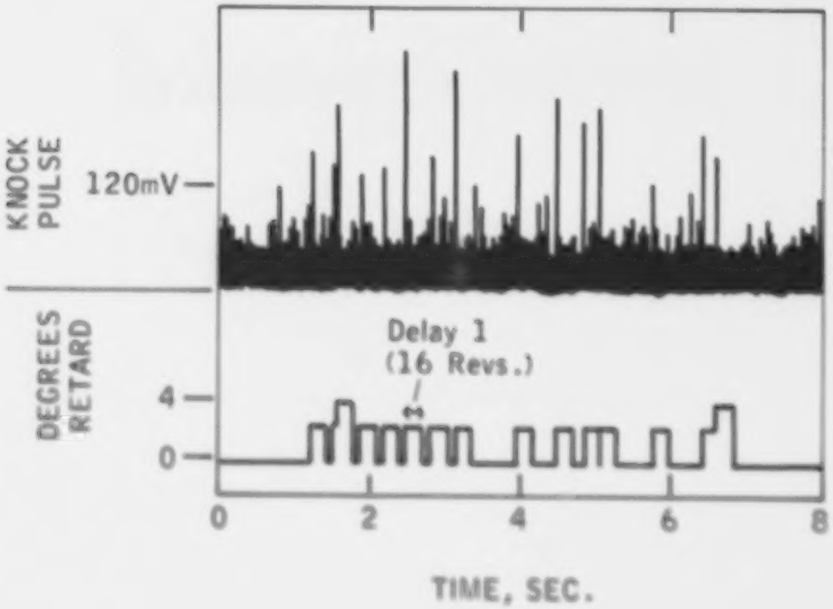


FIGURE 5-21

TOP - KNOCK SIGNAL VS. TIME DURING 40-60 MPH ACCELERATION USING KNOCKING FUEL WITH CONTROLLED SPARK TIMING

BOTTOM - SPARK RETARD WITH MEDIUM SPARK ADVANCE DELAY TIMES

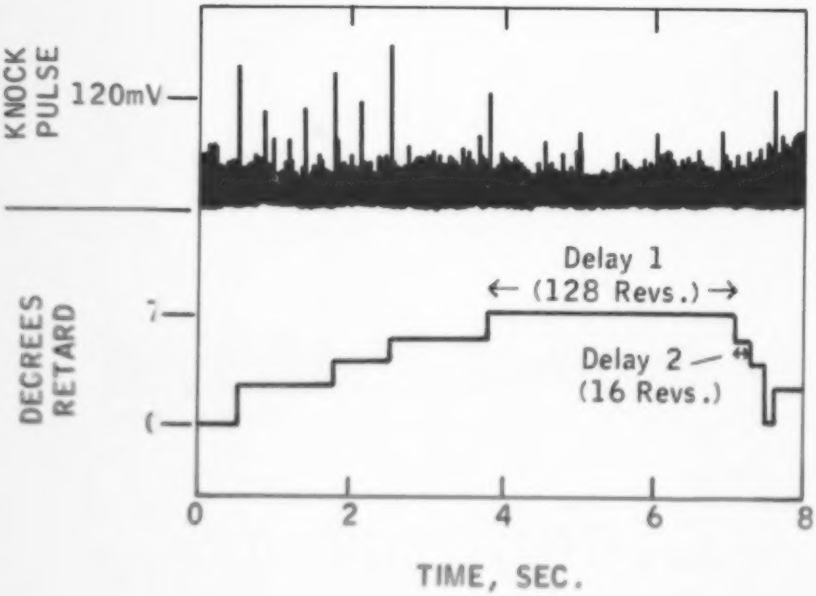
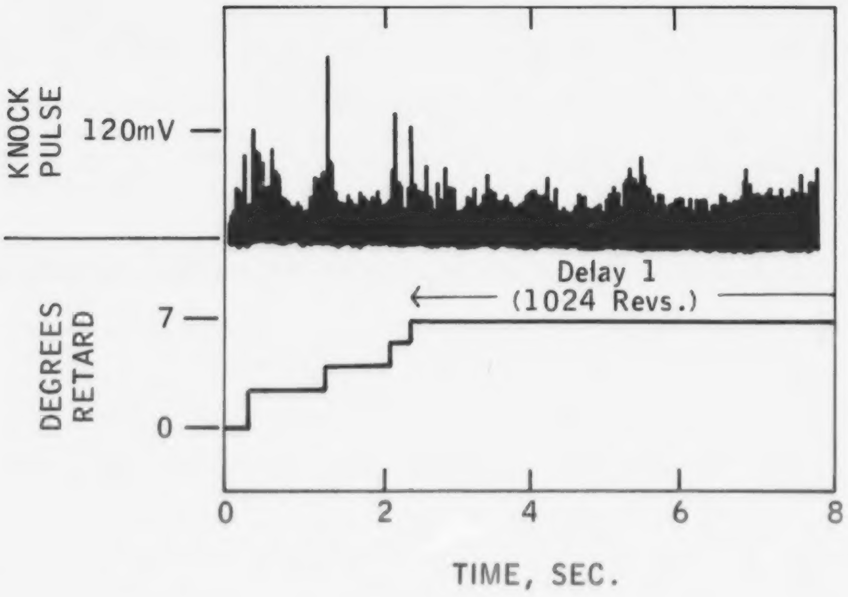


FIGURE 5-22

TOP - KNOCK SIGNAL VS. TIME DURING 40-60 MPH ACCELERATION USING KNOCKING FUEL WITH CONTROLLED SPARK TIMING

BOTTOM - SPARK RETARD WITH LONG SPARK ADVANCE DELAY TIMES



KNOCK SENSOR ACTUATED SPARK RETARD SYSTEM OPERATION - The knock sensor (piezoelectric crystal transducer) located on the passenger side cylinder head is wired into the piezotron coupler. This coupler contains three 8.4 volt batteries as shown in Figure 5-23 which should be checked periodically to insure that each has not dropped below 7.0 volts. The on/off switch on the coupler is used to cut off the signal and thus can be used to run the car with and without the knock sensor controlling the spark timing.

The entire system is shown in Figure 5-24. The output from the accelerometer coupler is fed to the controller. The controller is powered by a DC power supply and needs a minimum of 15 volts to operate. Generally the batteries are replaced when the voltage drops to around 17 volts.

The controller itself contains all the electronic hardware of the system and was built to allow sufficient flexibility during the research to obtain the optimum working system. Beginning from the upper left hand corner of Figure 5-25 and proceeding from left to right, these are the functions:

(1) Auto/Manual - allows either automatic or manual gain control.

(2) 1st Step - adjusts the size of the retard for 1st step only, normally set at 2.5° crank angle.

(3) Thresh - adjust threshold level for knock perception.

(4) Deg/k - used to adjust total maximum retard - normally 10° crank angle.

(5) Syn knk - punched to apply to a synthetic retard.

(6) MV/G - used to adjust gain when manual gain control is used.

(7) Frequency - center frequency of filter, normally set at 5350 Hz.

(8) Bandwidth of filter, normally set at 540 Hz.

(9) Control knob - off means no power to box standby and bypass are used for diagnostics and allow box electronics to function with no retard effected on engine. Control is the normal setting used to have spark control when piezotron coupler is on. If coupler if off, no spark control is obtained since accelerometer signal is disconnected. Set thresh turns meter into 0-200 mv meter for adjusting threshold. All the uncontrolled spark cases in our work were run with the knob in the control position with the coupler turned off.

(10) Decay and Delay - used to adjust the delay before spark advance is begun after last spark retard implemented.

$\frac{\text{Decay x Delay}}{8}$ = Delay -1 before initial advance in engine revolutions
Where F is an empirically-determined correction factor for the delay knob setting. F, which ranges between 1 and 2, can be read off the curve shown in Figure 5-26.

$\frac{\text{Decay}}{4}$ = Delay -2 before subsequent advances in engine revolutions

For our work, the optimal settings were a Delay of 4 and Decay of 128.

(11) Selector Switch - for using either 4 or 6 steps of spark retard.

(12) Meter - to read degrees of retard implemented.

(13) Output Taps - for diagnostic purposes.

(14) Cancel Retard - button which cancels immediately any applied retard.

(15) Sensor Input - lead from accelerometer.

(16) Ignition - input and output leads to and from distributor.

FIGURE 5-23

PIEZOTRON COUPLER

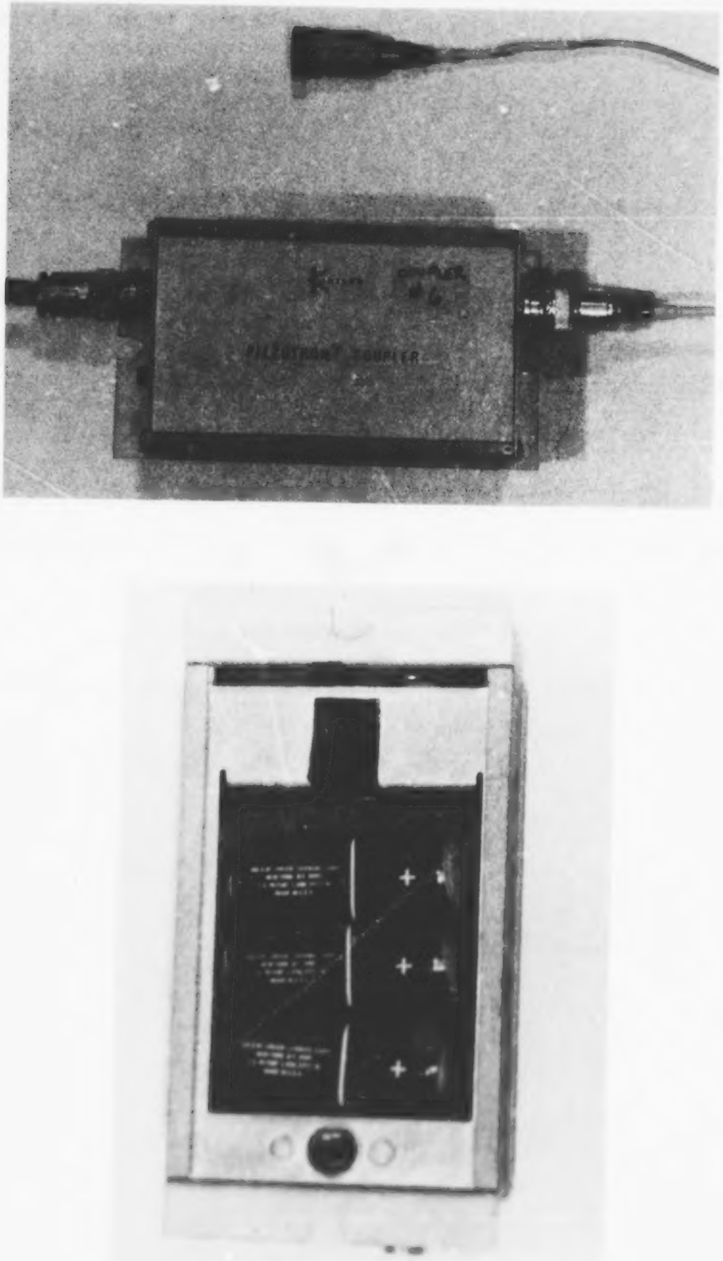

COUPLER #6
PIEZOTRON COUPLER

FIGURE 5-24

ENTIRE SYSTEM

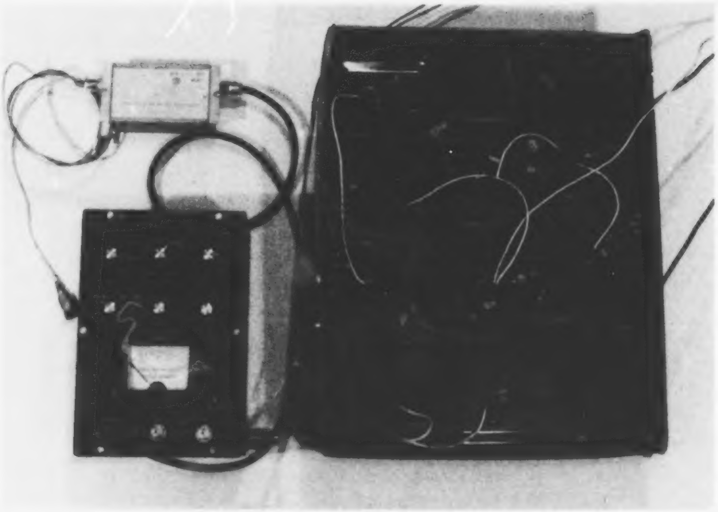


FIGURE 5-25

CONTROLLER

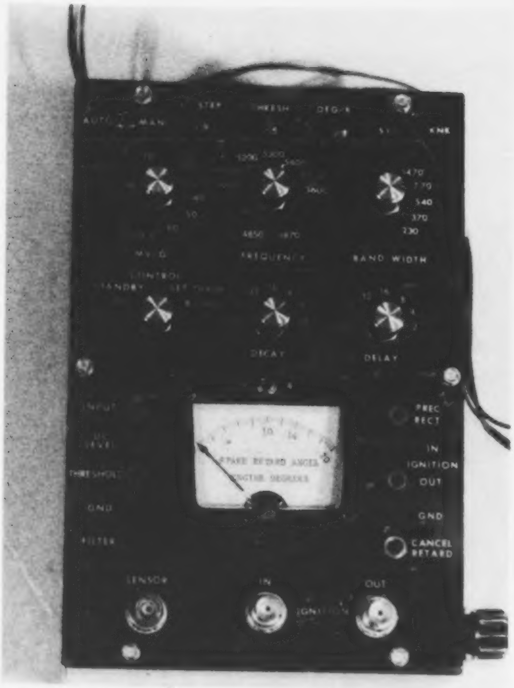
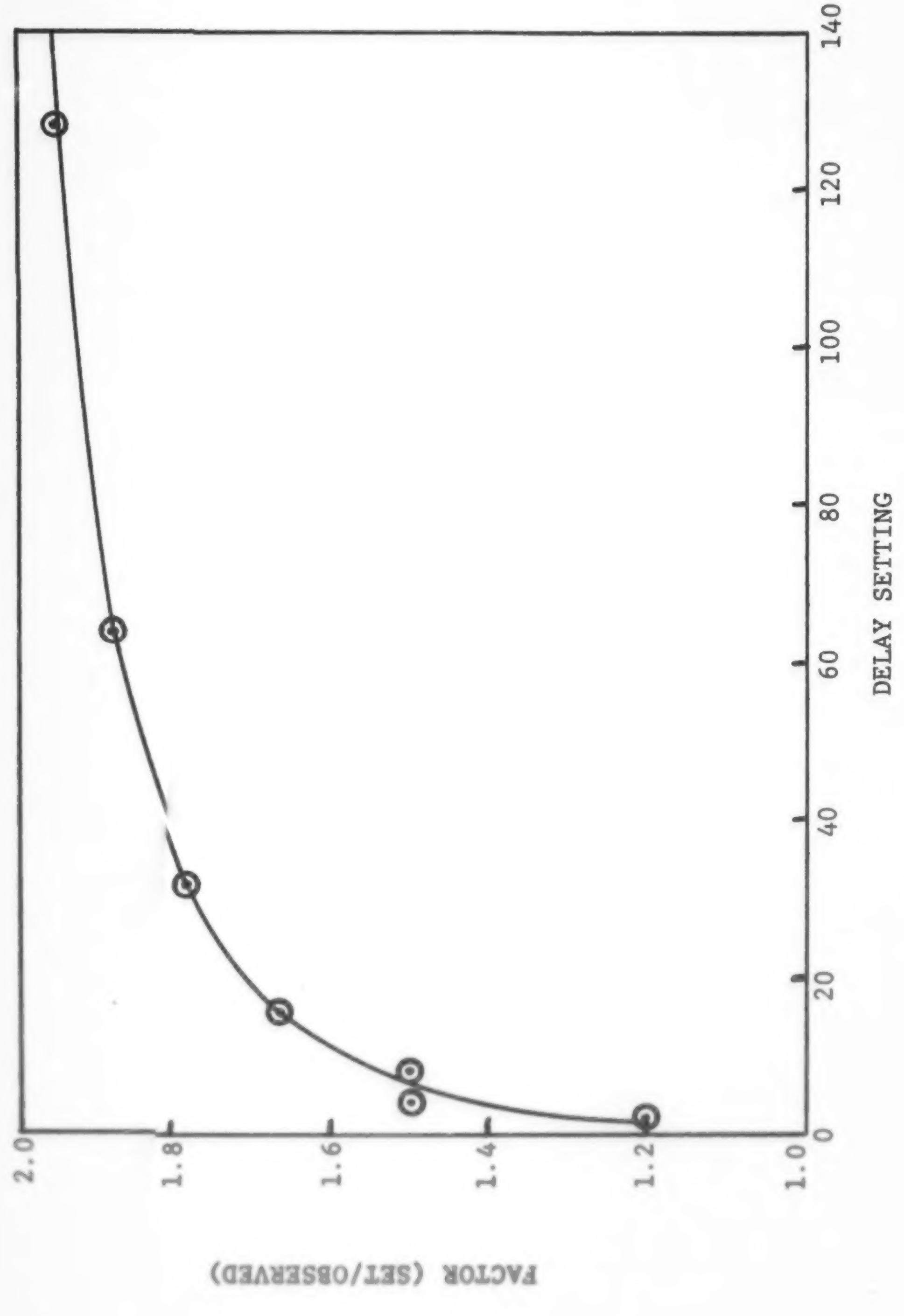

AUTO
MAN
STEP
THRESH
DEG/R
KNK
1200
3300
3600
4850
4870
1470
770
540
370
230
MV/G
FREQUENCY
BAND WIDTH
CONTROL
STANDBY
SET THRESH
DECAY
DELAY
INPUT
DC LEVEL
THRESHOLD
GND
FILTER
10
14
SPARK RETARD ANGLE
ENGINE DEGREES
PREC RECT
IN
IGNITION
OUT
GND
CANCEL RETARD
SENSOR
IN
IGNITION
OUT

FIGURE 5-26

CORRECTION FACTOR (F) FOR DELAY SETTING



SECTION 6

MODIFICATIONS TO VEHICLE

The base vehicle (1975 California Chevrolet Nova - 350 V-8 engine) was to be modified to 9:1 C.R. At this higher compression ratio, it was necessary to recalibrate the engine to the 1975 California emissions standards. With these modifications made, the fuel economy benefit was measured at 9:1 C.R. and compared to 8:1 C.R. The vehicle was then equipped with the knock sensor-spark retard system which had been demonstrated to be an effective means of reducing octane requirement in engine dynamometer testing.

6.1 EFFECTS OF INCREASED COMPRESSION RATIO

The base vehicle had a production 350 CID V-8 (California) engine with an 8:1 compression ratio. A 9:1 compression ratio can be achieved by replacing the standard heads with those from the 1969 10.25:1 C.R. engine. Compression ratios were determined by measurement of the combustion chamber volumes at top and bottom dead center by liquid displacement. These measurements were made for the 1975 blocks containing standard and notched pistons. Notched pistons were used so that the dual ignition heads would have enough clearance when coupled with the standard 350 CID block (see Figure 6-1). The effect of the piston cavity on compression ratio was less than 0.1 C.R. unit as shown in Table 6-1.

Table 6-1 Combustion Chamber Volumes of 350 CID Engine

	1975 Heads, cc.		1969 Heads, cc.	
Volumes	Standard	With Piston Cavities	Standard	With Piston Cavities
TDC	102.5	103.3	88.4	89.2
BDC	817.1	817.9	803.0	803.8
C.R.	7.97	7.92	9.08	9.01

The 1969 heads have about 35% greater squish area (the areas of heads in Fig. 6-2 which come in closest proximity to piston at TDC). A comparison between the base 8:1 C.R. engine and a modified engine with the 1969 heads at an 8:1 C.R. (obtained through the use of head spacers), showed no effect of the increased squish area on octane requirement, emissions, and fuel economy as shown in the section on the effects of increased turbulence on octane requirement. Thus, any effects on emissions, fuel economy, or octane requirement produced by using the 1969 heads are due only to the change in compression ratio. These effects are described below.

EMISSIONS - Emissions results are shown in Table 6-2. For each case, the tabulated data are the average of at least three emissions tests using Indolene (a high octane unleaded) fuel. The details of the emissions tests, including individual bag results for the FTP cycle are given in Appendix B. NO_x emissions increased with an increase in compression ratio (see Table 6-2, cases #1 and 2). Since emissions were to be controlled at the base case level, it was necessary to increase the exhaust recycle flow. The standard EGR valve was replaced with an exhaust back pressure-modulated valve which gave somewhat higher recycle flow with increased engine speed. The fraction of recycle was increased over all operating regimes by enlarging the area of the control orifice until NO_x emissions were lowered to the base 8:1 C.R. level as shown in case 3 of Table 6-2. Photographs of the proportional EGR valve showing the removable orifices are given in Figure 6-3. The recycle flow as percentage of intake was calculated to be 7% at 30 mph and 12% at 50 mph. This calculation was based on CO_2 measurements in the exhaust crossover and intake manifold corrected for H_2O content. Somewhat leaner choke settings was also employed. The comparison of cases 1 and 3 shows that the 9:1 C.R. emissions can be maintained at the 8:1 C.R. level by modification of the exhaust recycle system.

Table 6-2 Comparison of FTP Emissions for 8:1 and 9:1 Configurations

			Emissions - g/mile		
Case	C.R.	EGR	CO	HC	NO_x
1	8:1	Standard	6.0	0.5	1.7
2	9:1	Standard	8.1	0.6	2.2
3	9:1	Proportional(1)	3.9	0.5	1.7
4	9:1(2)	Proportional(1)	4.8	0.8	1.9
5	9:1(3)	Proportional(1)	4.9	0.7	2.0

---

(1) EGR flow proportional to engine speed. Orifice size increased from 1/4" to 21/64" diameter to increase flow. Choke a little leaner.

(2) Rings changed, new 1969 heads installed.

(3) After 12,000 miles.

FIGURE 6-1

350 CID ENGINE BLOCK WITH NOTCHED PISTONS

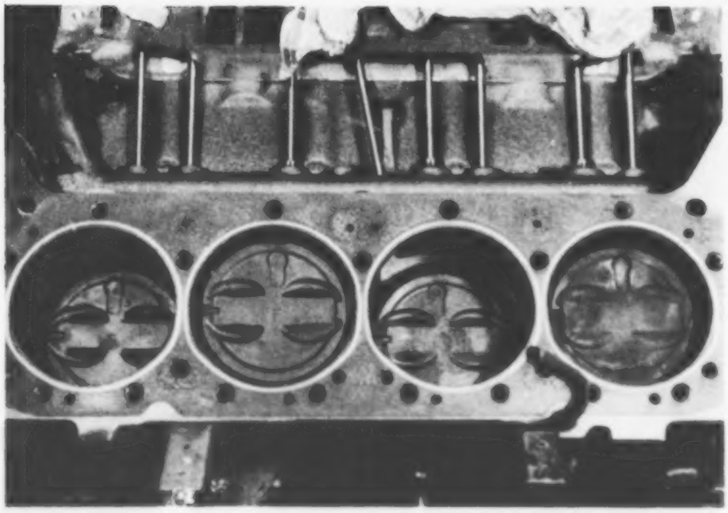
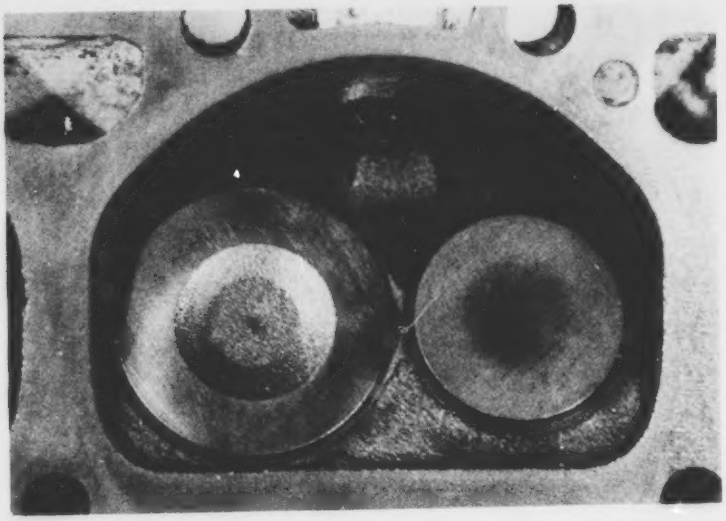
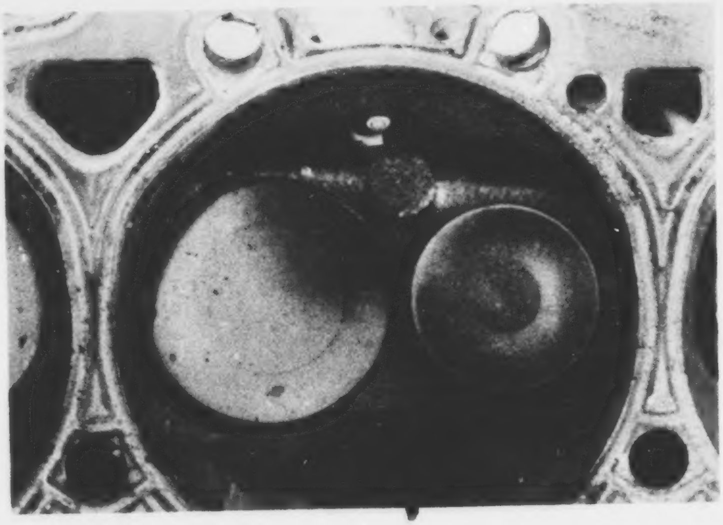


FIGURE 6-2

PHOTOGRAPHS OF 1975 AND 1969 350 CID HEADS



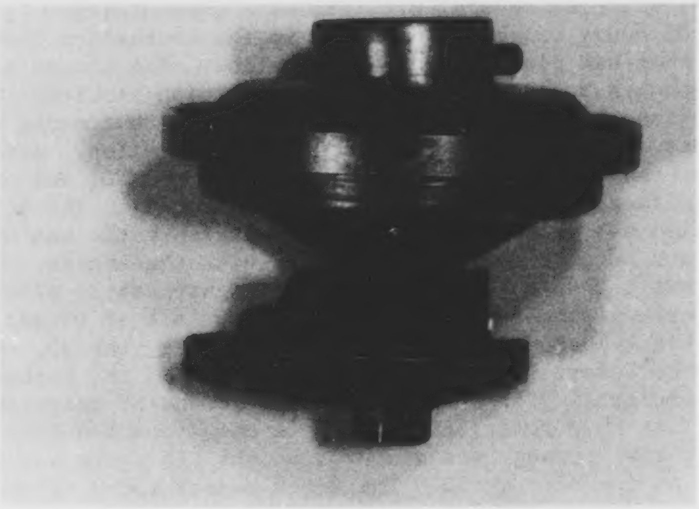
1975 Head

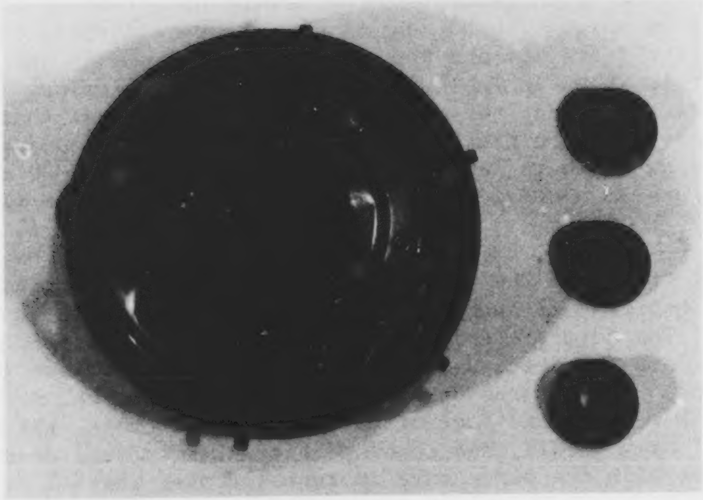


1969 Head

FIGURE 6-3

GM PROPORTIONAL EGR VALVE





Orifices

After these initial comparisons were completed, work began to evaluate the knock sensor system on the vehicle. During this period when the knock sensor-actuated spark retard system was being optimized for use on the vehicle, several problems were encountered. First, the accumulation of heavy oil-based deposits in the combustion chamber necessitated that new piston rings be installed. The accumulation of these ashy deposits presented some surface ignition problems which were accentuated by spark retard. The cylinder heads were cleaned of deposits and new pistons and rings were installed at 16,500 miles. After a 350 mile break-in, the emissions testing showed that the NO_x and hydrocarbon emissions were increased considerably (see Table 6-3). The octane requirement also was much higher. The compression ratio was measured at 8.8-9.0/1 and no problems could be found with the engine. It was apparent, however, that the engine had been significantly altered and therefore the old pistons were put in with a new set of rings. After a 1,200 mile break-in to assure proper ring seating, the NO_x emissions were found to be lower. It was necessary to rebuild the carburetor and adjust the choke setting to achieve the same CO and HC emissions as shown in Table 6-3. At this point, the vehicle's emissions had been recalibrated. Slightly lower fuel economy was measured on the FTP cycle but somewhat higher values on the HFET cycle. The knock sensor-spark retard system was re-installed and work on optimization was resumed. When this was completed, the heads were removed to scrape combustion chamber deposits so that clean engine initial requirement data could be obtained. At this time, severe valve recession was noted. The valve seats were more than twice as wide as in the new engine. This was presumably due to the fact that the 1969 heads were not induction hardened and therefore were more vulnerable to wear with unleaded fuel. New 1969 heads and valves were installed at 21,600 miles, which again resulted in an engine different in operation than the previous ones. The NO_x emissions were recalibrated by changing the size of the EGR orifice and the carburetor was rebuilt and adjusted. The end result is shown in Table 6-3. Although the emissions levels were successfully recalibrated, the fuel economy was lower than that obtained previously, especially on the FTP cycle. At the start of durability testing, emissions were as shown in Table 6-2, case 4 and after 12,000 miles with the spark control system operative little change had taken place (Table 6-2, case 5).

FUEL ECONOMY - The purpose of increasing the compression ratio was to obtain better fuel eocnomy. The fuel economy results are given in Table 6-4. The complete emissions data are given in Appendix B. Here the tabulated data represent averages of at least three tests in which the fuel economy was measured by three methods - carbon balance from emissions, fuel weight, and fuel metering. For each case, the average city (FTP), highway (HFET), and combined city/highway fuel economies are given along with the percentage improvement over the 8:1 C.R. case for the combined city/highway values. Case 2 shows that a one unit compression ratio change resulted in a significant benefit, both on the

FTP and HFET cycles. A 5.6% combined fuel economy benefit was measured for this vehicle, which is in the range of historically measured fuel economy benefits for a one C.R. unit change (7,8). This is the best estimate of the increase in fuel economy resulting from the unit C.R. change which can be made from our data since the runs were made back-to-back with only the heads being changed. Case 3 shows the effect of the addition of the proportional recycle system with increased EGR flows and somewhat leaner choke setting. Almost all the additional fuel economy benefit is seen in the FTP cycle.

As mentioned previously, two engine problems developed which necessitated the replacement of piston rings and the installation of new cylinder heads. The fuel economy data including these changes are given in Table 6-4, case 4. These changes, particularly the head replacement, resulted in significantly lower fuel economy. The final case (#5) gives the fuel economy data after 12,000 miles on the vehicle with new heads and rings.

OCTANE REQUIREMENT - An increase in vehicle octane requirement generally accompanies an increase in compression ratio. Based on historical data, a one unit increase in compression ratio should result in a 3-4 number octane requirement increase (7).

The octane ratings were done using three series of rating fuels, identical to those used in the CRC procedures. These are of two types: primary reference fuels and full boiling range fuels. The latter are classified by sensitivity: a high sensitivity (CX) series, which averages 10 and is 7 for the lowest octane fuels and increases to 12 for the highest octane fuels, and a lower sensitivity (C) series, ranging from 6 to 10 with an 8 average. A complete summary of these full-boiling rating fuels and octane rating procedures is given in Appendix C.

The clean engine research octane requirements, obtained during 40-70 mph wide open throttle (WOT) accelerations in high gear, are given in Table 6-5 for the 8:1 C.R. and the two 9:1 cases. The initial 8:1 to 9:1 (case #2) comparison showed a 4-6 number requirement increase. The octane requirement for the engine with new heads and rings (case 3) is two numbers higher than the 8:1 C.R. case. This engine subsequently was equipped with the knock sensor-actuated spark retard system used to control the vehicle's octane requirement during the accumulation of 16,000 miles.

Table 6-3 Comparison of Emission, Fuel Economy and Octane Requirement

		During Troubleshooting Period					
		Emissions (FTP) g/mile			Fuel Economy -g/mile		Octane Requirement
Mileage	Condition	CO	HC	NO_x	CVS-CH	HFET	(PRF)
14,000	8:1 C.R.-Base Vehicle Standard EGR Valve	6.0	0.5	1.7	11.4	16.3	80
15,000	9:1 C.R.-Proportional EGR	3.9	0.5	1.7	12.6	17.6	86
16,500	9:1 C.R.-New Pistons + Rings -Proportional EGR	6.3	0.9	2.6	11.9	18.2	90
18,500	9:1 C.R.-Old Piston + New Rings -Proportional EGR	4.0	0.6	2.0	12.0	18.1	88
22,600	9:1 C.R.-New 1969 Heads -Proportional EGR	4.8	0.8	1.9	11.5	17.3	84

Table 6-4 Comparison of Fuel Economy for 8:1 and 9:1 C.R. Configurations

Case	C.R.	EGR	Fuel Economy - mpg FTP	HFET	Combined	% Improvement Over 8:1 C.R.
1	8:1	Standard	11.4	16.3	13.2	---
2	9:1	Standard	12.0	17.5	13.9	5.6%
3	9:1	Proportional(2)	12.6	17.6	14.5	9.6%
4	9:1(3)	Proportional(2)	11.5	17.3	13.5	2.4%
5	9:1(4)	Proportional(2)	11.8	17.2	13.7	3.9%

---

(1) Calculated from $1/(0.55/\text{mpg}_{FTP} + 0.45/\text{mpg}_{HFET})$

(2) EGR flow proportional to engine speed. Orifice size increased from 1/4" to 21/64" diameter to increase flow. Choke one notch leaner.

(3) New rings installed, new 1969 heads installed.

(4) After 12,000 miles.

Table 6-5 Research Octane Requirement of Vehicle on Mileage Accumulation Dynamometer (MAD)

Case	C.R.	EGR	Primary Reference Fuels	Full Boiling Range Reference Fuels High Sensitivity - CX(2)	Full Boiling Range Reference Fuels Low Sensitivity - C(2)
1	8:1	Standard	80	83	82
2	9:1	Proportional(1)	86	87	86
3	9:1(3)	Proportional(1)	82	85	84

---

(1) EGR flow proportional to engine speed. Orifice size increased from 1/4" to 21/64" diameter to increase flow.

(2) See Appendix C.

(3) Rings and heads replaced.

6.2 EVALUATION OF SPARK CONTROL SYSTEM ON VEHICLE

Prior to the evaluation of the spark control system on the vehicle, the system was optimized. This procedure is discussed in detail in this laboratory evaluation section on knock sensor-actuated spark retard. The system as tested on the vehicle included automatic gain control, a filter of 5.35 kHz center frequency and 580 Hz bandwidth, and adjustable threshold and spark advance delay time settings. The spark retard was implemented in six distinct steps up to a maximum of 10° crank angle retard, with the initial retard being 2.5° and each additional one being 1.5°. The effects of the knock sensor-actuated spark retard system on vehicle octane requirement, acceleration performance, emissions, and fuel economy are discussed below.

OCTANE REQUIREMENT OF THE VEHICLE - The octane requirement of the vehicle was determined during 40-70 mph accelerations with wide open throttle (WOT) in high gear. The vehicle was checked to insure that its maximum octane requirement was at WOT and was not at part throttle or in second gear. Octane ratings were made using standard CRC reference octane fuels and were conducted both on the mileage accumulation dynamometer (MAD) and on the road at a test track. The rating designations are as follows: no knock (NK), trace minus (T^-), is the lowest perceptible knock detectable by a trained octane rater and is defined as the technical octane requirement of the vehicle, trace (T), trace plus (T^+) - typically lowest level noticed by average customer, very light (VL), very light plus (VL^+), light minus (L^-), light (L), light medium (LM), and heavy knock. Generally, anything above very light plus knock is not rated because it is quite loud. The octane requirement data are summarized in Table 6-6. The requirements

Table 6-6 Research Octane Requirement of 9:1 C.R. Vehicle (Clean Engine)

	Reference Fuel(1)	Normal Spark Timing	Knock Sensor Controlled Spark Timing(2)
Road	CX	85	82
	C	83	80
	Primary	82	80
MAD	CX	85	82
	C	84	81
	Primary	82	81

(1) See Appendix C.

(2) Delay 1 is 1,024 engine revolutions, Delay 2 is 32 engine revolutions.

given with the normal spark timing schedule are the requirements of the vehicle for trace minus (T^-) level knock. The octane rating quoted for the control system case is the lowest octane fuel which produces T^- knock excluding the initial detonation. The initial detonation may become quite intense with lower octane fuels. However, after the control system responds to it, only T^- to T knock usually is heard with fuels several octane numbers lower than the normal requirements. Using these criteria, a reduction in vehicle octane requirement of one to three numbers can be achieved depending on which fuel series was used. This reduction in octane requirement was approximately the same whether the vehicle was rated on the MAD or on the road.

The detailed test results both for the MAD and road octane ratings are given in Appendix C. The system threshold is set to detect T^- to T level knock. Thus, after the initial burst of knock, the system allows only T^- to T level knock to be heard audibly for several octane numbers below the normal requirement.

PERFORMANCE OF THE VEHICLE - The performance of the vehicle was evaluated by measuring acceleration times during octane rating at the test track for 40-70 mph, 0-60 mph, and 1/4 mile accelerations. These tests were conducted both with and without the spark control system to determine the effect of the applied spark retard on the vehicle's performance.

In Figure 6-4, 40-70 mph WOT acceleration times are plotted against octane number for the C series (lower sensitivity) rating fuels. It can be seen that there is a performance debit associated with the use of the controlled spark retard system when long spark advance delay times are used. For a fuel that is five numbers below the normal no knock requirement fuel, 16% slower acceleration times were observed.

The performance of the vehicle during 0-60 mph and quarter mile WOT accelerations was measured using CX-84 fuel which gave trace plus intensity knock on these accelerations. With this fuel, only very small performance debits were observed (see Table 6-7).

Table 6-7 Acceleration Performance of Vehicle Using Knocking - High Sensitivity CX - 84 RON Fuel

	0-60 mph	1/4 Mile
Uncontrolled Spark	10.4 sec	17.7 sec
Controlled Spark	10.6 sec	18.3 sec

VEHICLE MILEAGE ACCUMULATION - In order to assess the durability of the knock sensor-actuated spark retard system, 16,000 miles was accumulated on a mileage accumulation dynamometer (MAD). The cycle for the first 12,000 miles consisted of combined city-suburban driving with an average speed of 32 mph. For the last 4,000 miles, the AMA durability cycle was used. Properties of the mileage accumulation fuel, which was blended to be a minimum octane specification unleaded fuel, are given in Table 6-8. Octane requirement, emissions, and fuel economy were measured at 0, 6,000, 8,000, 10,000, 12,000 and 16,000 miles. During this period of mileage accumulation, any spark retard occurring over the driving cycle was recorded continuously on a strip chart recorder. Initially, some problems were encountered with spurious retard from electrical interference when the controller was powered by an AC power supply. Operation with a 15 volt DC power supply essentially eliminated these spurious retards. After these problems were corrected, only 29 spurious retards were recorded over the 16,000 miles, due in part to non-vehicle electrical intereference and possibly some engine noises.

Table 6-8 Properties of Mileage Accumulation Fuel

Research Octane Number	91.8
Motor Octane Number	82.5
Lead - g/gal.	<0.01
Sulfur, ppm	237
API Gravity @ 60°F	60.8
FIA: Aromatics	22.5%
Olefins	14.5%
Saturates	63.0%
RVP	7.3 psi
IBP	100°F
10%	138°F
50	215°F
90	331°F
F.B.P.	415°F

Octane Requirement and Performance - A plot of vehicle MAD octane requirement vs. accumulated mileage is given in Figure 6-5 for the 8-average sensitivity (C) fuel series including both the uncontrolled and the controlled spark cases. The octane requirement increased approximately 3 numbers over the 12,000 miles. It should be noted that the controlled spark timing case gave approximately a 3 number lower octane requirement than the no control case at all mileage intervals. This benefit is considerably less than that observed in the engine dynamometer evaluation. This may be due to the fact that knock is more difficult to hear in the engine dynamometer installation. Acceleration performance debits similar to those mentioned previously were measured with the spark timing controlled.

FIGURE 6-4

ACCELERATION PERFORMANCE (40-70 MPH) VS. RESEARCH OCTANE NUMBER FOR CLEAN ENGINE USING 8 SENSITIVITY (C SERIES) FUELS; FOR CONTROLLED SPARK CASE, DELAY 1 AND DELAY 2 ARE 1,024 AND 32 ENGINE REVOLUTIONS RESPECTIVELY

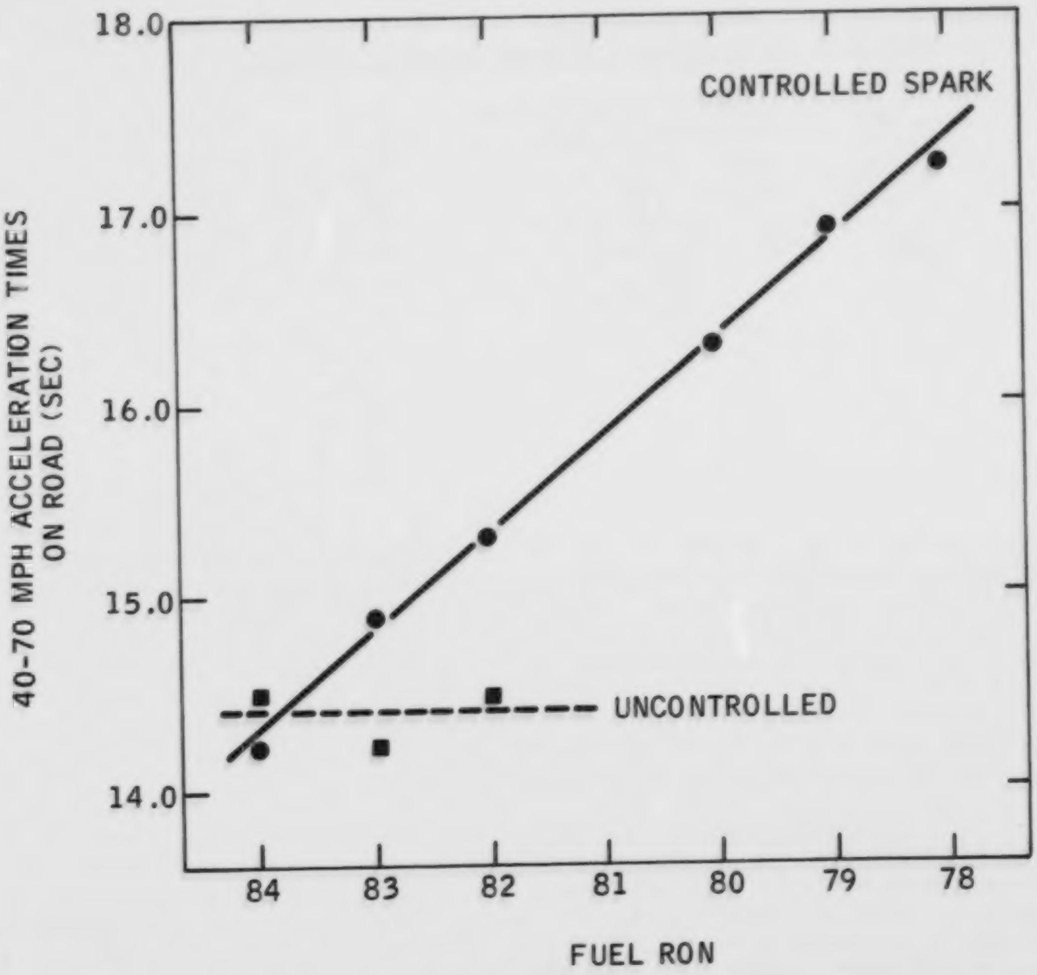
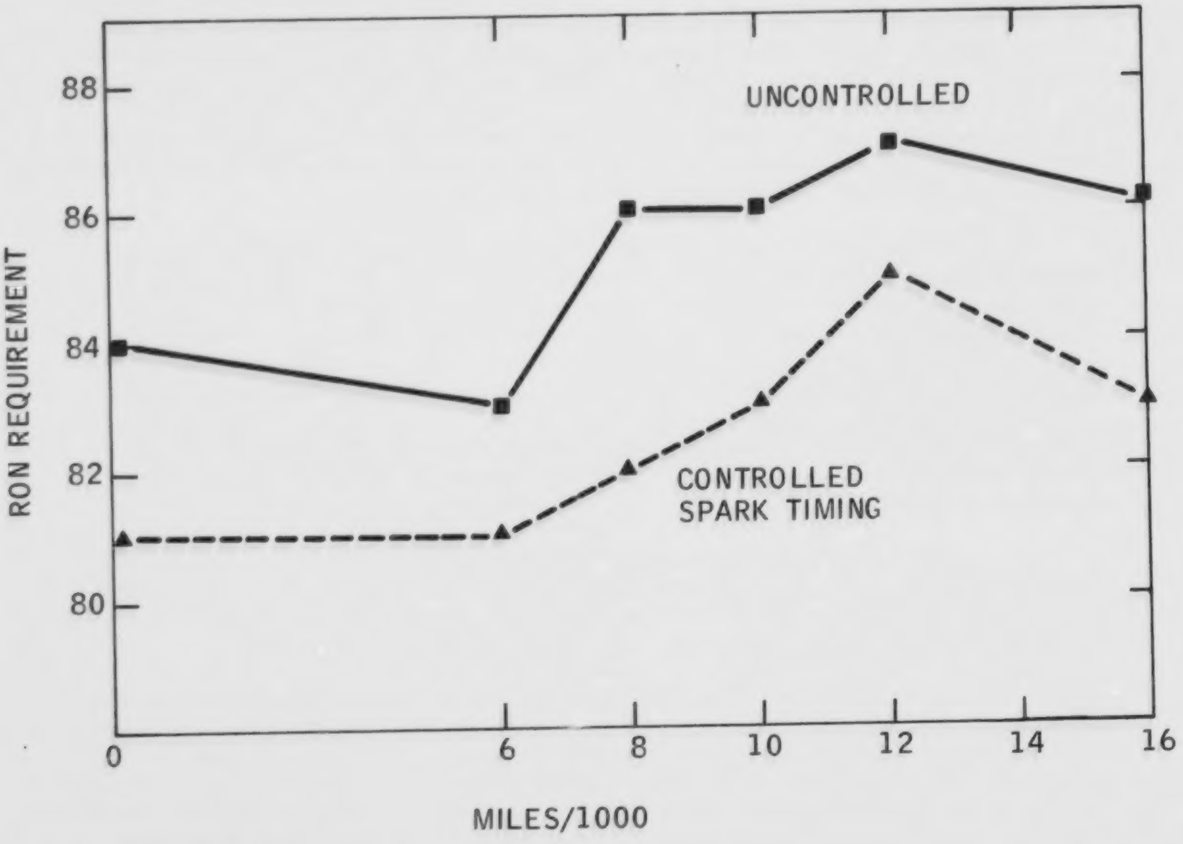


FIGURE 6-5

VEHICLE OCTANE REQUIREMENT WITH 8 SENSITIVITY (C) FUELS VS. ACCUMULATED MILEAGE FOR CONTROLLED AND UNCONTROLLED SPARK CASES; FOR CONTROLLED SPARK CASE, DELAY 1 AND 2 ARE 1,024 AND 32 ENGINE REVOLUTIONS RESPECTIVELY FOR THE FIRST 12,000 MILES AND ARE 128 AND 32 ENGINE REVOLUTIONS FOR THE LAST 4,000 MILES



The vehicle was also octane rated at the test track after the 12,000 mile accumulation. These octane requirement data are given in Table 6-9 for all three series of reference fuels. The 12,000 mile MAD data are also included for comparison. Approximately, a two number reduction in octane requirement was obtained with the controller operational, using long spark advance delay times.

At this time, it was noted that the accelerometer, located on the driver side head (rear) had lost some sensitivity. A new sensor was located on the passenger side head (rear). When the testing was repeated on the MAD with the new accelerometer, using the long countdown delays (1,024 and 32 engine revolutions respectively for initial and subsequent delays in spark advance), a three number benefit was observed (see Table 6-9). However, it was found that the threshold could be lowered for greater sensitivity to knock and shorter delays used (128 and 32 engine revolutions) which resulted in a two number octane reduction and considerably better acceleration performance of the vehicle.

During the last 4,000 miles on the AMA durability cycle, the shorter delay times and lower threshold were used since this seemed to give the best overall results (i.e., reduction of knock intensity and acceleration performance of vehicle). The octane requirement data at 16,000 miles is given in Table 6-10. Again a one to three octane number benefit can be attributed to the controlled spark case when the initial knocks are ignored. However, in this case of short delay times and low threshold, the knock intensity heard after the initial clatter can be controlled to the T to T^+ level even as low as 78 RON with acceptable acceleration performance.

The vehicle was octane rated on the MAD with three commercial unleaded fuels. All had greater octane quality than 92 RON. Since the vehicle requirement was so low, no knock was obtained for all three commercial fuels and, therefore, no spark retard was observed.

In Figure 6-6, the vehicle acceleration time on the MAD during 40-70 mph WOT accelerations is plotted against the research octane number of the fuel. Curves are shown for three cases: 1) uncontrolled spark timing, 2) controlled spark timing - 120 mV threshold-long countdown delays, and 3) controlled spark timing - 100 mV threshold-shorter countdown delay. No decrease in acceleration performance is seen with decreases in fuel octane for the uncontrolled case. For the controlled case with long countdown spark advance delays, a significant performance debit is seen, which is consistent with the road data shown in Figure 6-4. At 78 RON, 30% slower 40-70 mph acceleration times are observed. With this fuel, a trace plus to very light initial burst of knock causes a 5.5° retard followed by trace knock to a full 10° retard, eliminating the detonation but producing very long acceleration times. Another case of controlled spark timing with shorter countdown delays was run with a lower threshold (100 mV). With these settings, the same 78 RON fuel gives trace plus initial knock retarding to 7° and then intermittent trace knock as the spark timing continuously advances and retards in response to the accelerometer signal. With the 78 RON fuel, 7 numbers below the vehicle's no knock requirement, the level of knock can be

Table 6-9 Research Octane Requirement of 9:1 C.R. Vehicle After 12,000 Miles

Place	Location of Sensor*	Reference Fuel	Uncontrolled Spark	Controlled Spark	Threshold (mV)	Spark Advance Delay (Engine Revolutions)	
						1	2
MAD	Driver Side	Primary	84	82	120	1024	32
		C	87	85			
		CX	86	84			
Road	Driver Side	Primary	81	79	120	1024	32
		C	81	80			
		CX	84	82			
MAD	Passenger Side	C	83	80	120	1024	32
MAD	Passenger Side	C	83	81	100	128	32

* Sensor located on rear of head with axis parallel to crankshaft.

Table 6-10 Research Octane Requirement of 9:1 C.R. Vehicle After 4,000 AMA Durability Cycle*

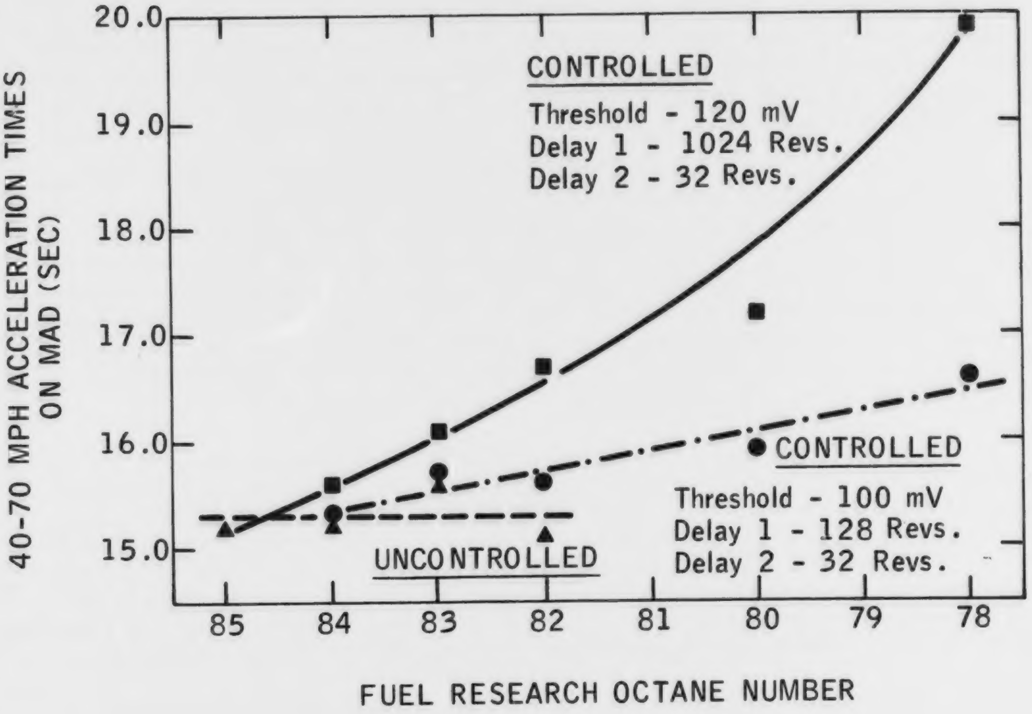
	Reference Fuel	Uncontrolled Spark	Controlled Spark
MAD	C	86	83
	P	82	81
Road	C	83	82
	P	83	82
	CX	85	∿82

---

* Spark Advance Delays of 128 and 32 engine revolutions, threshold - 100 mV.

FIGURE 6-6

ACCELERATION PERFORMANCE (40-70 MPH) VS. RESEARCH OCTANE NUMBER AFTER 12,000 MILES USING 8 SENSITIVITY (C) FUELS FOR UNCONTROLLED CASE, AND CONTROLLED CASES WITH SHORT AND LONG SPARK ADVANCE DELAYS



held to trace with only a 9-10% performance debit. Road tests also showed approximately a 10% performance debit with controlled spark and very low octane fuels (see Appendix C).

The 1/4 mile and 0-60 mph acceleration times, on the road after the 12,000 mile accumulation using the longer delay times and after 16,000 miles using the shorter delay times and lower threshold setting, are given in Table 6-11. These data indicate that the vehicle is not significantly affected by spark retard on these types of accelerations, as was seen previously before mileage accumulation, although the overall acceleration performance even with no spark control deteriorated (compare with Table 6-7).

Emissions and Fuel Economy - Emissions and fuel economy were measured in duplicate at 6,000, 8,000, and 10,000 miles and in triplicate at 0 and 12,000 and 16,000 miles. The averages of these data are plotted in Figure 6-7 for emissions and Figure 6-8 for fuel economy. Due to the piston and head changes and mileage accumulated during break-in and testing, the catalyst was used for approximately 7,000 miles at the start of the "zero" mile testing.

The zero mile testing was done with uncontrolled spark timing. All subsequent testing was with the controller with spark advance delays set for 1,024 and 32 engine revolutions for the first and subsequent steps respectively. During this phase a total of 9 FTP-HFET sets were run with only 2 total retards occurring. Both of these occurred during the 57 mph cruise portion of HFET cycle. Since Indolene fuel ($\underset{\sim}{\sim}$98 RON) was used for these tests, it can be assumed that no knock was present. Thus, these 2 retards are from some other source, i.e., extraneous electrical or other engine noises.

At 8,000 miles, the idle CO was leaned somewhat and the carburetor was cleaned. This may account for the reduced CO emissions levels shown in Figure 6-7. At 12,000 miles, new plugs were installed due to oil fouling. Oil consumption over the 16,000 miles averaged 0.9 quarts/1,000 miles. Except for the deviations in CO at 6,000 miles and HC at 10,000 miles (subsequently corrected by the new spark plugs), the vehicle emissions remained below the California standards of 9.0 g CO/mile, 0.9 g HC/mile, and 2.0 g NO_x/mile through the 16,000 miles accumulated.

Referring to Figure 6-8, the fuel economy improved on both cycles after the carburetor cleaning and idle CO leaning prior to 8,000 mile testing. When the spark plugs were replaced prior to the 12,000 mile testing, the fuel economy improved, especially on the FTP. These final 16,000 mile fuel economies show a 4% combined fuel economy benefit over the base 8:1 C.R. unmodified vehicle with no deposits accumulated.

Comparison of Mileage Accumulation Results with Those From 8:1 C.R. Vehicle - A comparison of the final MAD octane requirement, emissions levels and fuel economies is given in Table 6-12 for the 8:1 and 9:1 C.R. vehicles. The 8:1 C.R. vehicle had a 12 number octane requirement increase (ORI) during mileage accumulation resulting in a 91 RON requirement. In contrast, the 9:1 C.R. modified vehicle finished at 86 RON with only a 2 number ORI. The requirement with the knock sensor operational was 83 RON. This is quite a low requirement especially

Table 6-11 Acceleration Times on Road with Controlled Spark

Accumulated Miles	Fuel	Quarter Mile Retard	Quarter Mile Rating	Quarter Mile Time	0-60 mph Retard	0-60 mph Rating	0-60 mph Time	Delay (Engine Revs.) 1	Delay (Engine Revs.) 2
12,000	CX 84 (Knocking)	5.5°	T^+	18.6	5.5°	T^+	12.0	1024	32
	CX 100 (No Knock)	0°	NK	18.6	0°	NK	11.8		
16,000	CX 84 (Knocking)	7°	T^+	18.3	7°	T^+-VL	11.8	128	32
	CX 100 (No Knock)	0°	NK	18.4	0°	NK	11.5		

FIGURE 6-7

FTP EMISSIONS VS. ACCUMULATED MILEAGE

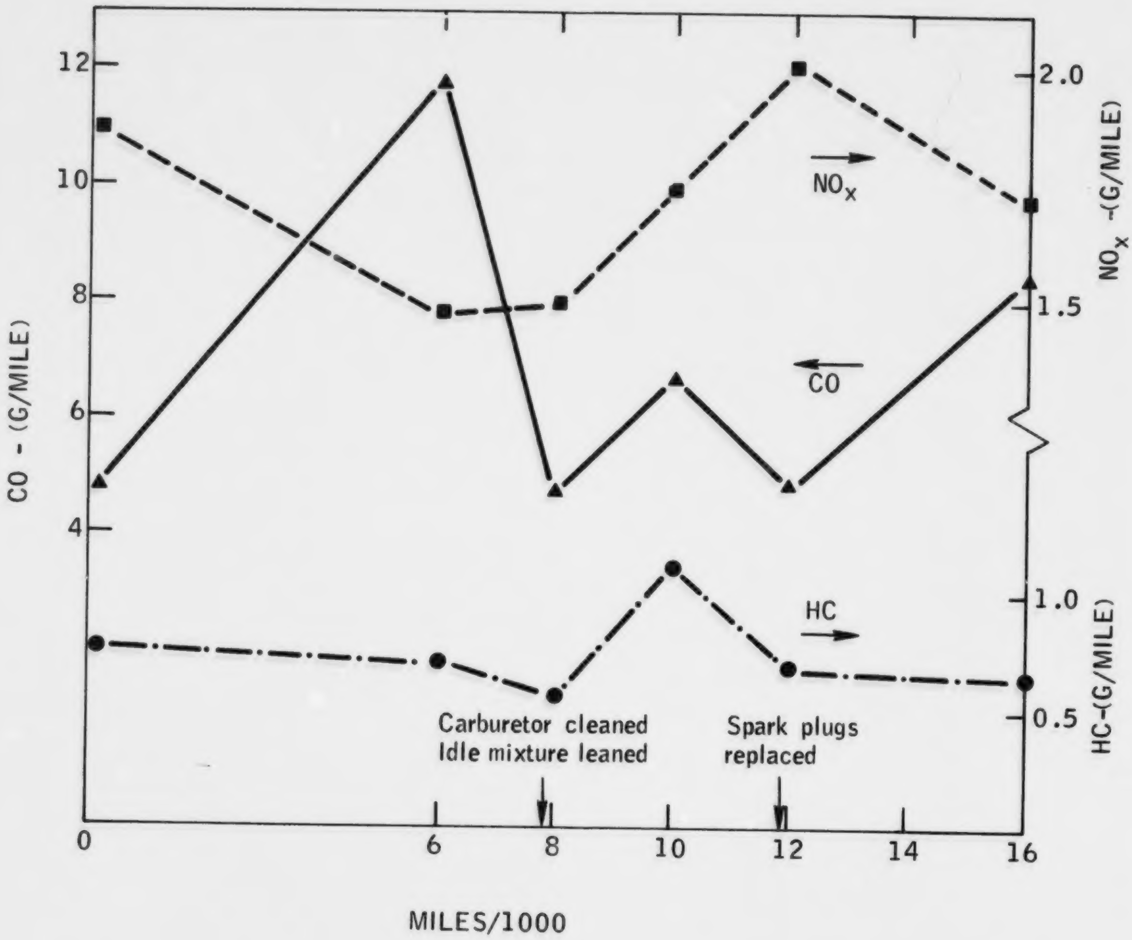
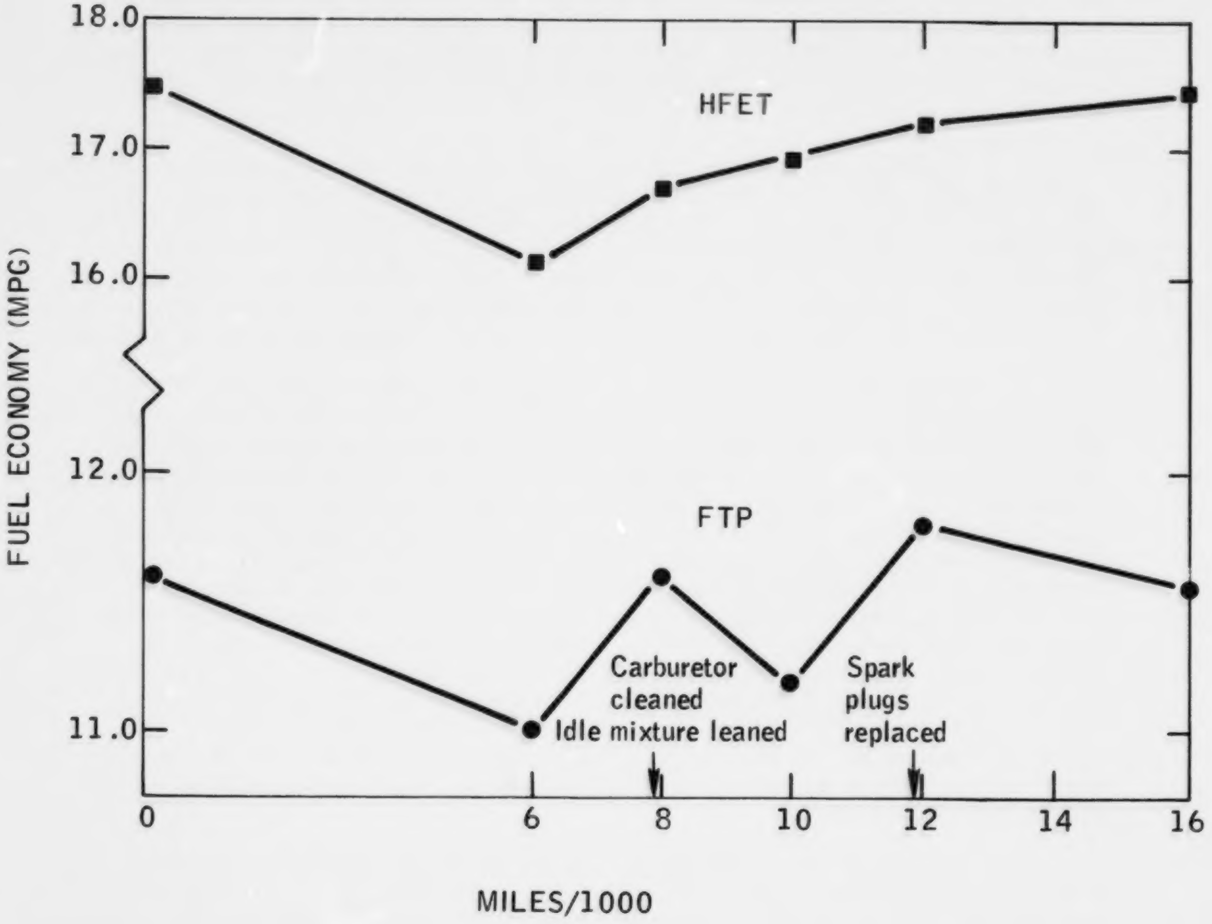


FIGURE 6-8

FTP AND HFET FUEL ECONOMY VS. ACCUMULATED MILEAGE



for a 9:1 C.R. vehicle. The primary factor is the low ORI. ORI can vary considerably from engine to engine even within one engine type, so this result is not surprising. Fuel composition also affects ORI. However, the fuels used for these two sets of mileage accumulations were blended as identically as possible and should not be a factor. The low requirement appears to be characteristic of this particular vehicle.

The emissions data show that the base 8:1 C.R. vehicle failed the 2.0 g/mile NO_x standard after mileage accumulation while the modified 9:1 C.R. vehicle passed. The 9:1 C.R. fuel economy values are lower on the FTP cycle and higher on the HFET cycle than the 8:1 C.R. data. When weighed to get the city/highway composite fuel economy, the two cases are virtually identical.

It needs to be pointed out, however, that the two engines compared here are quite different due to the drastic changes that occurred during the course of the program. The 9:1 C.R. case represents an engine which has different pistons and rings than the 8:1 C.R. engine. Furthermore, the carburetor was rebuilt several times. Thus, although the values listed in Table 6-12 accurately represent the final vehicle conditions at 8:1 and 9:1 C.R., the comparison between the two leaves much to be desired.

EMISSION AND FUEL ECONOMY TESTING WITH LOW OCTANE FUEL - Tests were run to determine whether or not a fuel which knocked during WOT octane ratings and produced spark retard would also cause retard on the FTP and HFET driving cycles and thereby cause significant changes in emissions or fuel economy. A fuel was chosen which gave trace level knock during 40-70 mph WOT accelerations on the MAD. The emissions and fuel economy data are tabulated in Table 6-13 for three cases: 1) Indolene fuel-long delay times, 2) C-82 (see Appendix C) fuel-long delay times, and 3) C-82 fuel-shorter delay times. No retards were observed on any of these emissions tests due to the mild acceleration conditions. In another test, where the ignition timing was advanced by 6° (12° BTC basic timing) and a 86 RON fuel was used (4 octane numbers below the no knock requirement), no retards were observed. This indicates that fuels two and four numbers below the vehicle's no knock requirement can be operated satisfactorily most of the time with occasional performance debits on severe accelerations.

OPTIMIZATION OF SYSTEM BY ADVANCING SPARK TIMING - Additional fuel economy benefit might be extracted by advancing the timing closer to MBT timing. Since an MBT distributor could not be obtained for the vehicle, the spark timing was advanced by 6° to 12° BTC basic timing to ascertain if additional fuel economy benefit was attainable without upsetting the emissions and octane requirement. The results of this testing are compared to the data obtained after the 4,000 AMA cycle in Table 6-14. The octane requirement increased by 3-4 numbers, and the NO_x emissions increased by 30%. The additional fuel economy benefit measured was 8% on the FTP cycle and 2% on the HFET cycle. However, the vehicle failed the NO_x standard.

Table 6-12 Comparison of Deposit - Accumulated 8:1 and 9:1 C.R. Engines

Vehicle	Octane Req.	ORI	Emissions			Fuel Economy	
			CO	HC	NO_x	CVS-CH	HFET
8:1 @ 13,000 miles	91	12	4.7	0.5	2.3	12.2	16.2
9:1 @ 16,000 miles	86(83)*	2	8.4	0.7	1.7	11.6	17.4

---

* Knock Sensor - Spark Retard System operational.

Table 6-13 Emissions and Fuel Economy Measurements of 9:1 C.R. Vehicles Using Low Octane Fuel (C-82)(1) After 12,000 Miles

Fuel	Delay (Engine Revolutions)		Threshold (mV)	FTP Emissions (g/mile)			Fuel Economy (mpg)		
	1	2		CO	HC	NO_x	FTP	FET	Combined(2)
Indolene	1024	32	120	4.9	0.7	2.0	11.8	17.2	13.7
C-82 RON	1024	32	120	5.3	0.5	1.9	11.3	16.8	13.2
C-82 RON	128	32	100	5.2	0.6	1.8	11.7	17.3	13.7

---

(1) Gives trace knock on WOT 40-70 mph accelerations.

(2) Calculated from $1/(0.55/\text{mpg}_{FTP} + 0.45/\text{mpg}_{HFET})$

Table 6-14 Comparison of Octane Requirement, Emissions and Fuel Economy for 12° BTC vs. 6° BTC Spark Timing

Basic Timing	Octane Requirement (C)		Emissions (g/mile)			Fuel Economy (mpg)	
	Uncontrolled	Controlled Spark	CO	HC	NO_x	CVS-CH	HFET
12° BTC	89	87	8.2	0.8	2.5	12.5	17.8
6° BTC	86	83	8.4	0.7	1.7	11.6	17.4

PROBLEMS ENCOUNTERED WITH SYSTEM - During the course of this work, several problems arose with the application of knock sensor-spark retard technology. These are discussed below to provide guidance for future work in this area.

Performance Debits - There are significant acceleration performance debits associated with using spark retard to eliminate most of the knock for several octane numbers below the engine's normal requirement. When long spark advance delay times were employed to realize a large reduction in total detonation heard, 10-30% slower acceleration times were obtained. However, limited testing indicates that if slightly higher levels of detonation are allowed, much lower performance debits are possible (on the order of 0-10% depending on how much detonation is permitted). This can be accomplished by raising the threshold so that the system is less sensitive to detonation, by decreasing the waiting period before advancing the spark schedule or by some combination of the two. Another technique to improve overall performance would be to sense the end of an acceleration, with an additional engine input, after which normal spark advance would be used. For example, use of a manifold vacuum or throttle position indicator would provide a signal whereby the end of an acceleration is well characterized, i.e., high manifold vacuum or closed throttle. This signal could be used to override the spark control system to immediately cut out any applied spark retard under conditions similar to these, thereby reducing excessively long periods of applied retard even though a long spark advance delay is used.

Spurious Retard - Occasionally, spurious retards were noted during the course of this work. Some of these were well defined extraneous electrical interference which could be corrected, such as moving any unnecessary AC-operated electronics out of the car, using DC-power for the controller itself, and removing tachometer leads from car. Others were ignored because they were not considered to be serious uncorrectable problems in a commercial unit, e.g., spark retards when cranking starter motor to start the engine. A more serious problem, which manifested itself just prior to replacing the cylinder heads with recessed valves, was that real engine noises other than knock could trigger the spark retard system occasionally. These retards were traced by listening to tape recordings slowed down to 1/16 of normal speed. In these recordings, knock is very apparent as a ringing drum-like sound and valve noises can be distinguished from it. A peculiar valve noise, which had some ringing character to it, occasionally produced a retard. These spurious retards could be eliminated by raising the threshold at the expense of lower sensitivity to knock. Since the heads were replaced, however, no retards of this type have been noted.

Surface Ignition - The accumulation of ashy oil-based deposits (40-50% ash) in the combustion chamber caused a significant surface ignition problem during one phase of the study. In fact, when the heads were removed, a large ashy particle was removed from the cylinder which had been knocking. In this case, spark retard actually made the surface ignition much worse, presumably due to the increased generation of heat in the engine. This would probably not be a general problem since surface ignition is rare with unleaded fuel. In this case, the severe driving schedule, i.e., more WOT accelerations, may have produced the high ash deposit problem due to high oil consumption.

Engine Overheating - Although tests were not made, the potential exists for engine overheating with long periods of running with retarded timing. This could occur either by a malfunction of the spark control system or by the use of a fuel of much lower octane quality than the engine's requirement. For this reason (and also for putting a limit on acceleration performance losses), only 10° maximum retard is allowed. This potential problem could probably be eliminated by using a coolant temperature sensor to override the spark retard system if high coolant temperatures occur.

6.3 DRIVEABILITY AND EVAPORATIVE EMISSION TESTING

EVAPORATIVE EMISSIONS - After the vehicle was modified to change the compression ratio to 9:1 and the tailpipe emissions were recalibrated to the base case level, evaporative emissions were measured in the SHED test. The data compiled in Table 6-15 are the averages of 3 tests and can be compared to that measured on the base vehicle. The diurnal emissions are approximately the same as that measured in the base case. However, the hot soak data are about 6 grams lower. The vehicle probably had a leak source which was corrected during the modifications to the vehicle to give the lower numbers.

Table 6-15 Evaporative Emissions of 1975 Chevrolet Nova (9:1 C.R.)

Grams		
Diurnal Cycle	Hot Soak	Total
1.4	3.0	4.4

DRIVEABILITY TESTING - Driveability testing was conducted on the 9:1 C.R. modified vehicle prior to the start of and at the completion of the 16,000 mile accumulation. These tests, which were done with the knock sensor-spark retard system operational, can be compared to those conducted prior to vehicle modification to see if any change in driveability had occurred. The test procedure and detailed data sheets are given in Appendix D. A summary of the results is given in Table 6-16 for the four specially blended driveability test fuels. The vehicle exhibited good driveability overall. Prior to mileage accumulation, the vehicle had some cold starting problems with Fuels D-2 and D-3. These cold starting problems were not as evident after the 16,000 mile accumulation during which time the carburetor was rebuilt.

Table 6-16 Summary of Driveability Test Results for 9:1 C.R. Modified Vehicle

	Fuel	Cold Start Stalls	Cold Start Retards	Warm Vehicle Stalls	Warm Vehicle Retards
Prior to 16,000 Mile Accumulation	D-1	0	0	0	0
	D-2	Hard Start	0	0	0
	D-3	6	0	0	0
	D-4	0	1(10°)	0	1(WOT)
After 16,000 Mile Accumulation	D-1	1	0	0	0
	D-2	0	0	0	1(WOT)
	D-3	1	0	0	0
	D-4	0	0	0	0

On only a single occasion a 10° retard was recorded during a period of poor cold driveability (i.e., stumbling and surging). It is assumed that the retards were in response to the poor vehicle driveability, since driveability problems have not been encountered due to the operation of the knock sensor in any of the vehicle octane ratings. On two occasions, a retard was noted on a wide open throttle acceleration after the vehicle was warmed up. This could be due to some engine combustion noise or knock. In general, though, little response was observed from the knock sensor actuated-spark retard system during these tests.

SECTION 7

KNOCK FREQUENCY ANALYSIS OF ALTERNATE ENGINES

A study was undertaken to examine knock frequency characteristics of other engines to determine whether the 5-5.5 kHz band was unique to the 350 CID engine. An attempt was made to obtain two engines which were very different than the 350 CID V-8 engine used in the program. The 2.3 liter 4-cylinder engine used in the Ford Pinto and the 2.8 liter V-6 engine used in the Ford Mustang-II were selected. A comparison of engine displacement, bore, and stroke is given in Table 7-1.

Table 7-1 Comparison Between 350 V-8 and 2.3 L and 2.8 L Engines

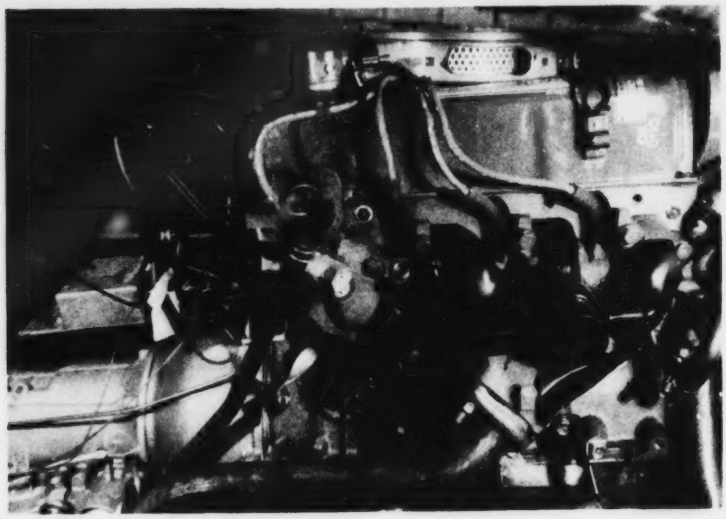
Engine	Displacement in^3	Displacement L	Bore	Stroke
Chevrolet V-8	350	5.7	4.0	3.5
Ford L-4	140	2.3	3.8	3.1
Ford V-6	171	2.8	3.66	2.7

It can be seen from the table that the engines are considerably different in design not just in total displacement. The standard straight 4 cylinder, V-6 and V-8 engines are represented by this group. In addition, the bore and strokes are different and thus individual cylinder dimensions are quite different. If significant changes in the frequency of knock were to be observed by changing the engine geometry, one would expect to see it with a comparison between these three engines.

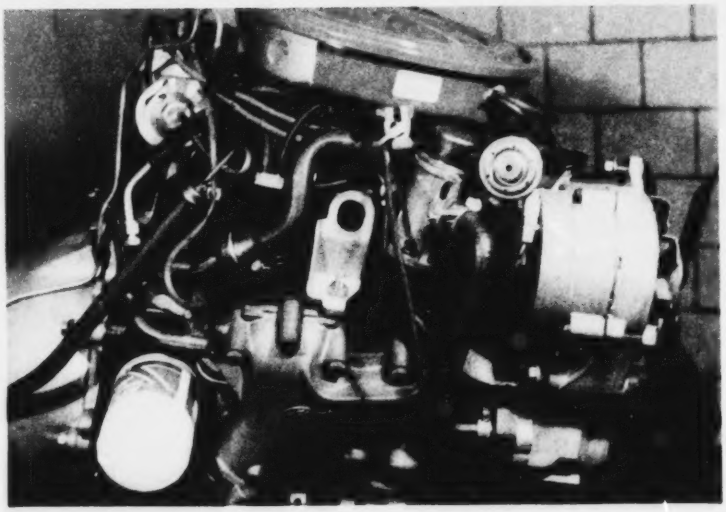
These engines were obtained from Ford Motor Company through EPA. Each engine was individually mounted in the engine dynamometer test stand with the associated automatic transmission. Photographs of these engines are shown in Figure 7-1. The cycle follower was programmed according to road load information that was available for each engine. Six accelerations were then mounted on the engine and after an initial 2-3 hour break-in period testing began. The testing, as in the case of the 350 CID engine, included steady state, fuel changeover, and acceleration runs to examine the knock frequency under a variety of different engine operating modes.

FIGURE 7-1

PHOTOGRAPHS OF ENGINE DYNAMOMETER
INSTALLATIONS OF 2.3 L AND 2.8 L ENGINES



2.3 Liter
L-4 Engine
(Pinto)



2.8 Liter
V-6 Engine
(Mustang-II)

7.1 FORD 2.3 LITER L-4 PINTO ENGINE

A 1978 2.3 liter engine complete with accessories and automatic transmission was mounted in the engine dynamometer stand after removing the air conditioning unit and power steering pump. A load curve as shown in Table 7-2 was programmed into the cycle follower.

Table 7-2 Load Curve Used for 2.3 L and 2.8 L Engines on Dynamometer Stand

Vehicle Speed (mph)	Road Horsepower
20	0
30	7.8
40	9.8
50	13
60	18

The critical loading particular for acceleration testing is the inertia loading. The inertia was set to give acceleration times equivalent to those obtained on a 2.3 L Pinto test vehicle on the MAD. For a 30- to 60-mph acceleration in top gear, this was approximately 33 sec. The test vehicle was also measured to determine the engine rpm equivalent of road speed so that our testing in the engine cell could be correlated with vehicle speed. These data are shown in Table 7-3.

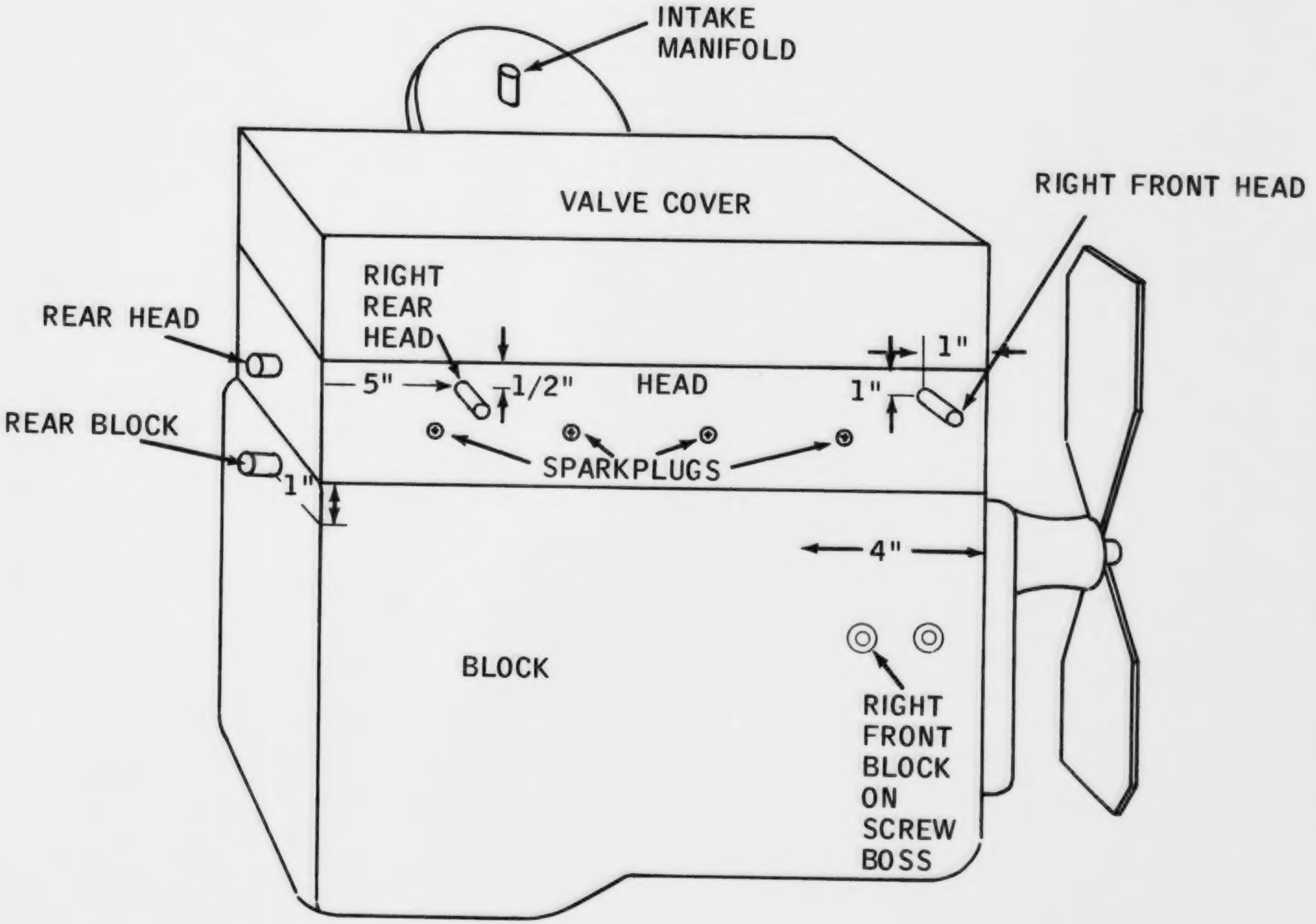
Table 7-3 Engine RPM Measured at Various Vehicle Speeds on Pinto

	Engine, RPM	
MPH	Acceleration	Steady State
30	1650	1650
35	2550	
40	2650	2100
45	2750	
50	2950	2650
55	3100	
60	3250	3200

A schematic showing the location of the six accelerometers tested on the 2.3 liter engine is given in Figure 7-2. Three accelerometers were located on the head, 2 on the block and 1 on the intake manifold. The output of these accelerometers was recorded on tape for specific operating conditions and representative segments of the recordings were frequency analyzed. For each of the test conditions shown below, recordings were made for a no-knock and a knocking fuel.

FIGURE 7-2

LOCATION OF ACCELEROMETERS ON
2.3 LITER 4 CYLINDER PINTO ENGINE (SIDE VIEW)


INTAKE MANIFOLD
VALVE COVER
RIGHT FRONT HEAD
RIGHT REAR HEAD
REAR HEAD
REAR BLOCK
5"
1/2"
HEAD
1"
1"
SPARKPLUGS
1"
4"
BLOCK
RIGHT FRONT BLOCK ON SCREW BOSS

1. Acceleration Tests - engine was accelerated from 30 to 60 mph at WOT.

2. Steady State Tests were run at 30 and 40 mph (1600 and 2600 rpm).

3. Fuel Change Tests were run at 40 mph with the fuel changed from VL knock to NK back to VL knock.

A complete set of the frequency analyses from the tests is given in Appendix F. For brevity, only a summary of these results is given here. A set of frequency analyses is given in Figures 7-3 to 7-8.

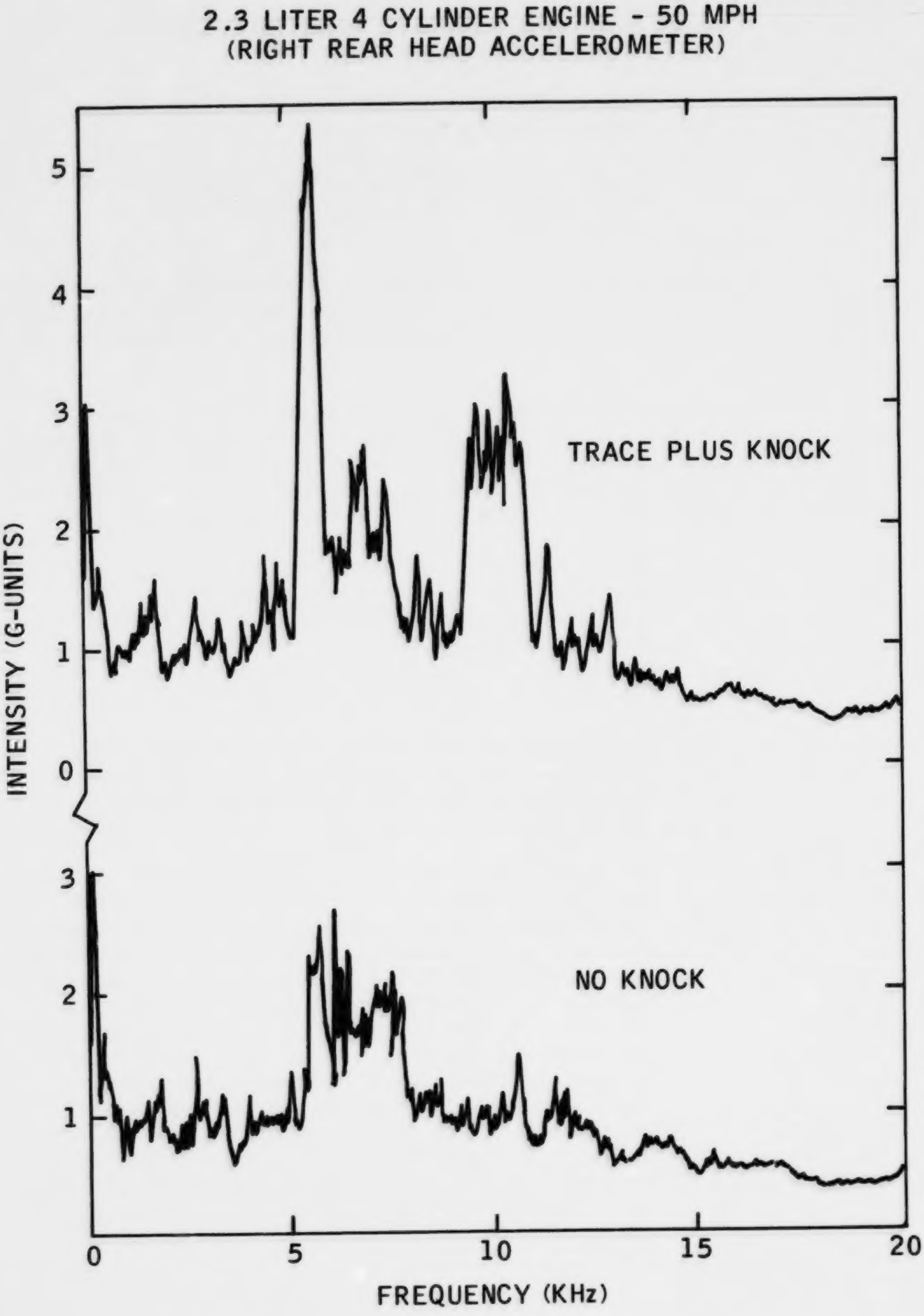
Each figure is a frequency analysis of an individual accelerometer signal recorded at 2600 rpm (50 mph) steady state operation for a trace plus knocking fuel and a no-knock fuel. The set contains a frequency analysis of each accelerometer location under these conditions. The following conclusions can be drawn from the data.

1. Trace plus knock intensity produces 2 to 4 G peaks. Background no-knock gives 1 to 2 G peaks. Thus, the engine appears to have considerable background noise to begin with. This may be due to the specific engine design (i.e. the overhead cam engine is noisier than most).

2. The rear head accelerometers (both axial and transverse to the crankshaft) gave the largest knock signals and thus would appear to be the ones to use for knock detection.

3. The axial rear head signals contain peaks at 5.4, 9.4, 11.0, and 13.5 kHz whereas the transverse accelerometer only showed 5.4 and 10.0 kHz peaks. The same peaks occur to a lesser degree in the no-knock recordings. The ratios of peak intensities between the knocking and no-knock runs are given in Table 7-4 for the 50 mph steady state and 30-60 mph acceleration runs. These data suggest that in the right rear head (transverse) recordings, the 5.4 and 10.0 kHz peaks had greater signal/noise ratios than the corresponding 5.4 and 9.4 peaks in the rear head (axial) recordings. With no other basis to use, the accelerometer with the greater signal/noise ratio would be chosen as the optional location.

FIGURE 7-3



2.3 LITER 4 CYLINDER ENGINE - 50 MPH
(RIGHT REAR HEAD ACCELEROMETER)

FIGURE 7-4

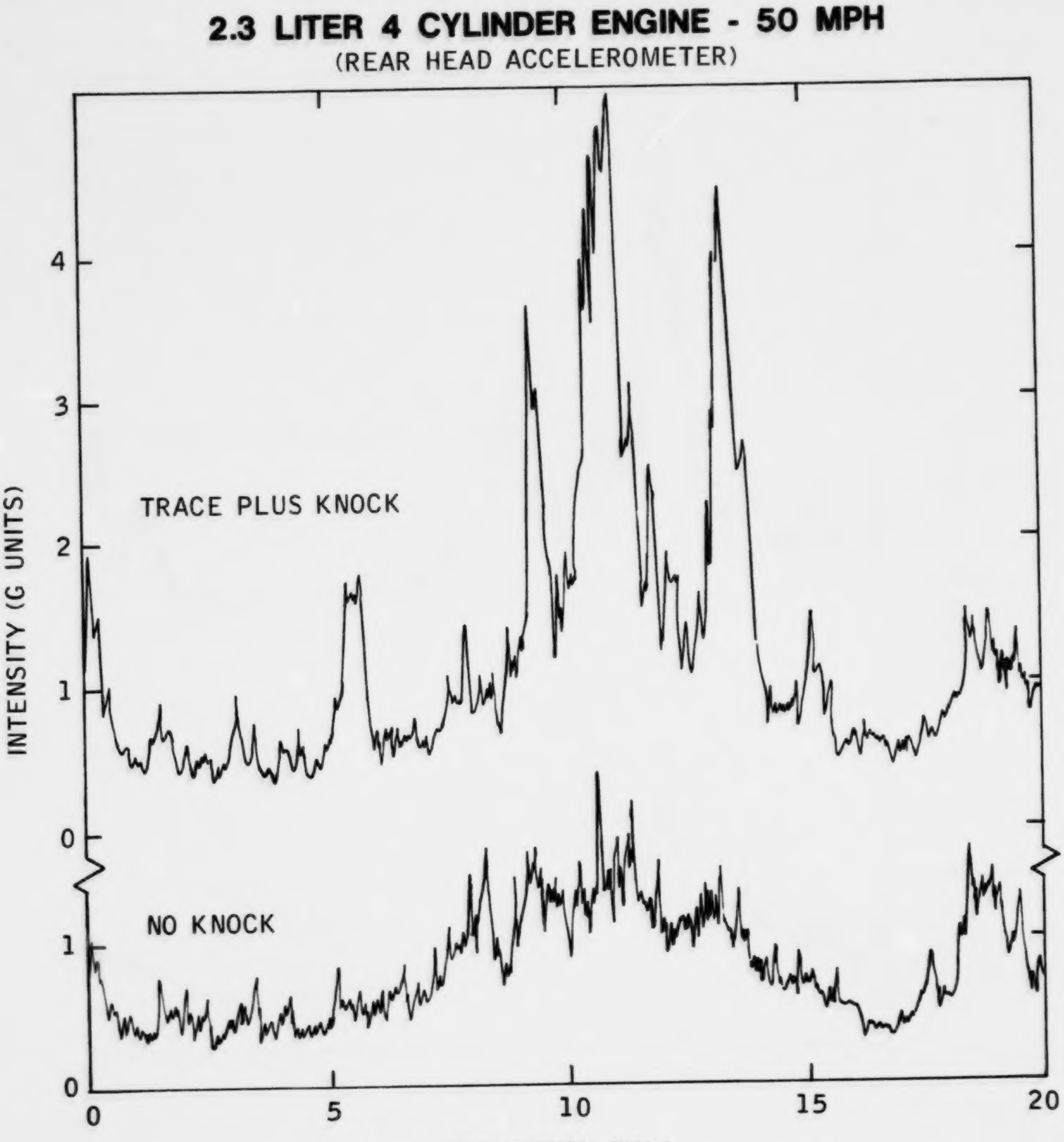

2.3 LITER 4 CYLINDER ENGINE - 50 MPH
(REAR HEAD ACCELEROMETER)
INTENSITY (G UNITS)
TRACE PLUS KNOCK
NO KNOCK
4
3
2
1
0
1
0
0
5
10
15
20
FREQUENCY (KHz)

FIGURE 7-5

2.3 LITER 4 CYLINDER ENGINE - 50 MPH
(REAR BLOCK ACCELEROMETER)

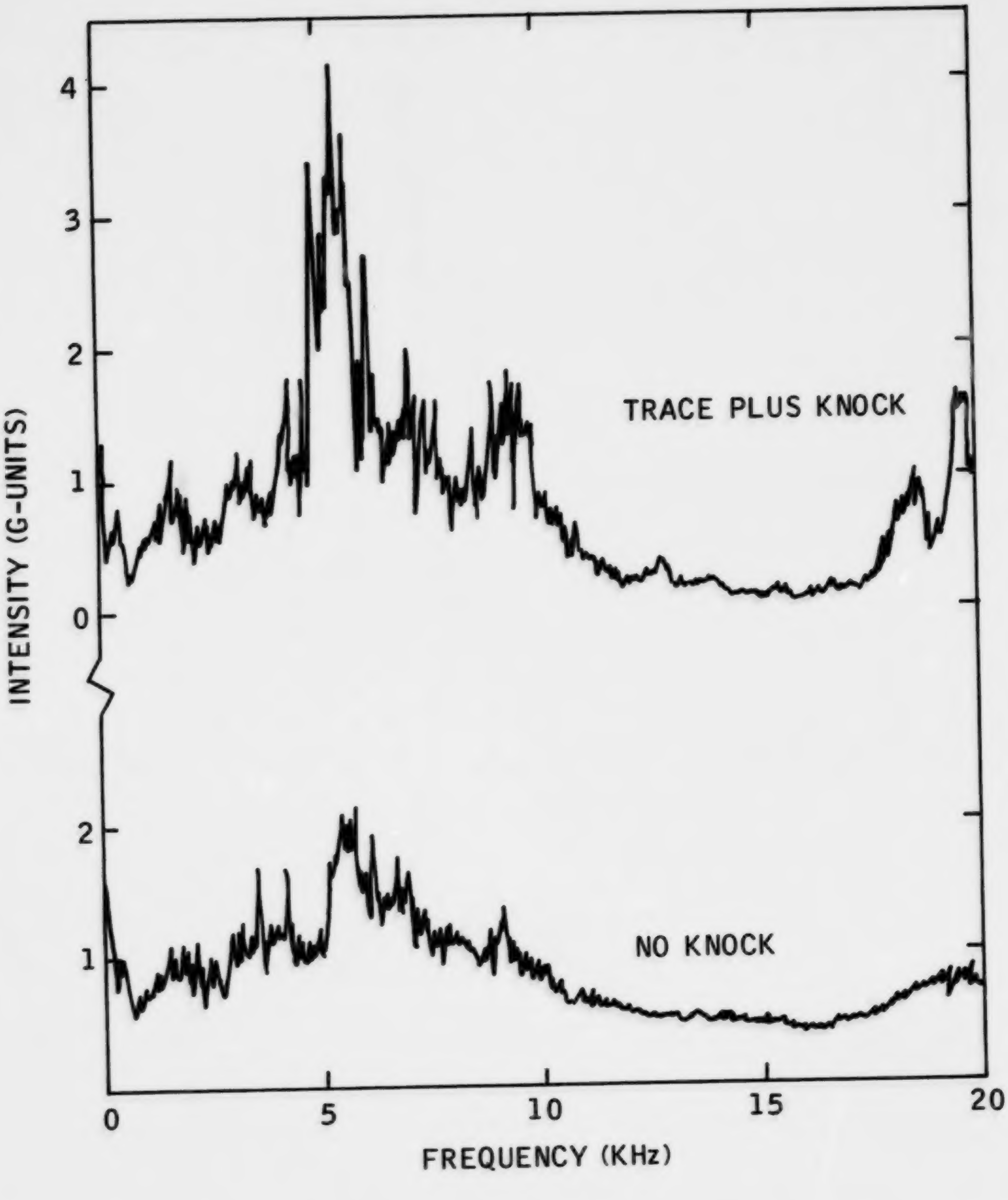


FIGURE 7-6

2.3 LITER 4 CYLINDER ENGINE 50 MPH
(INTAKE MANIFOLD ACCELEROMETER)

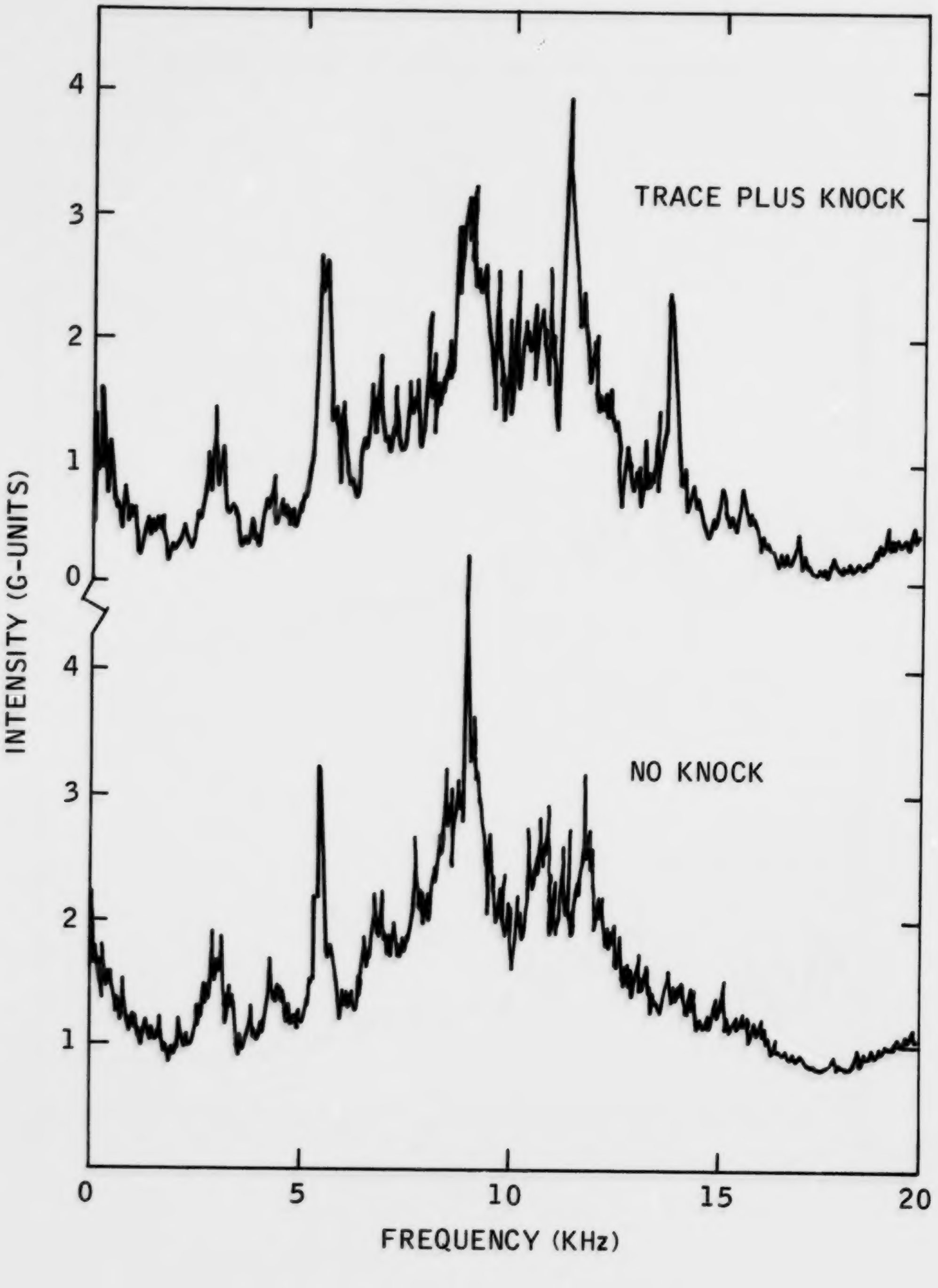


FIGURE 7-7

2.3 LITER 4 CYLINDER ENGINE - 50 MPH
(RIGHT FRONT HEAD ACCELEROMETER)

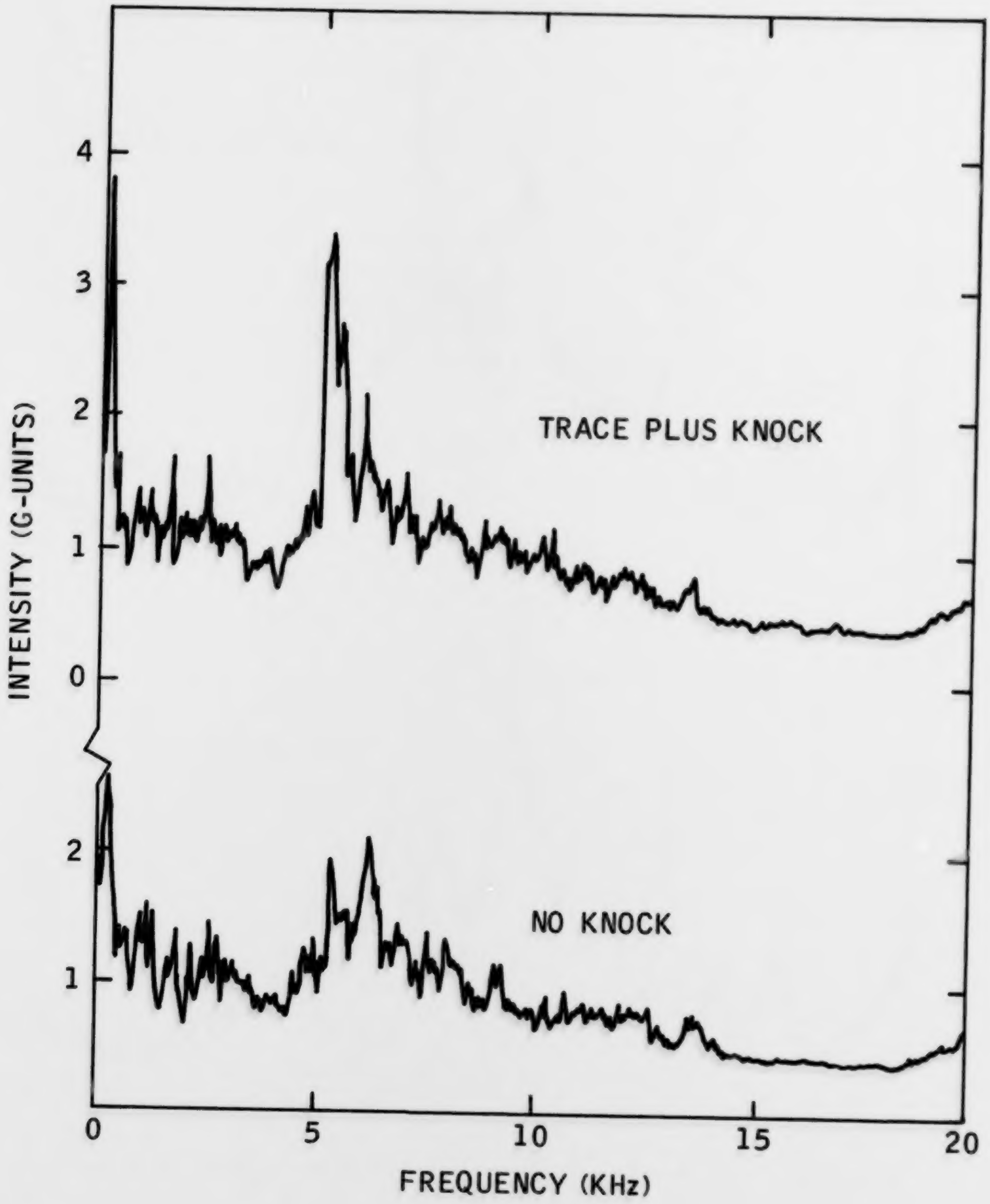


FIGURE 7-8

2.3 LITER 4 CYLINDER ENGINE - 50 MPH
(RIGHT FRONT BLOCK ACCELEROMETER)

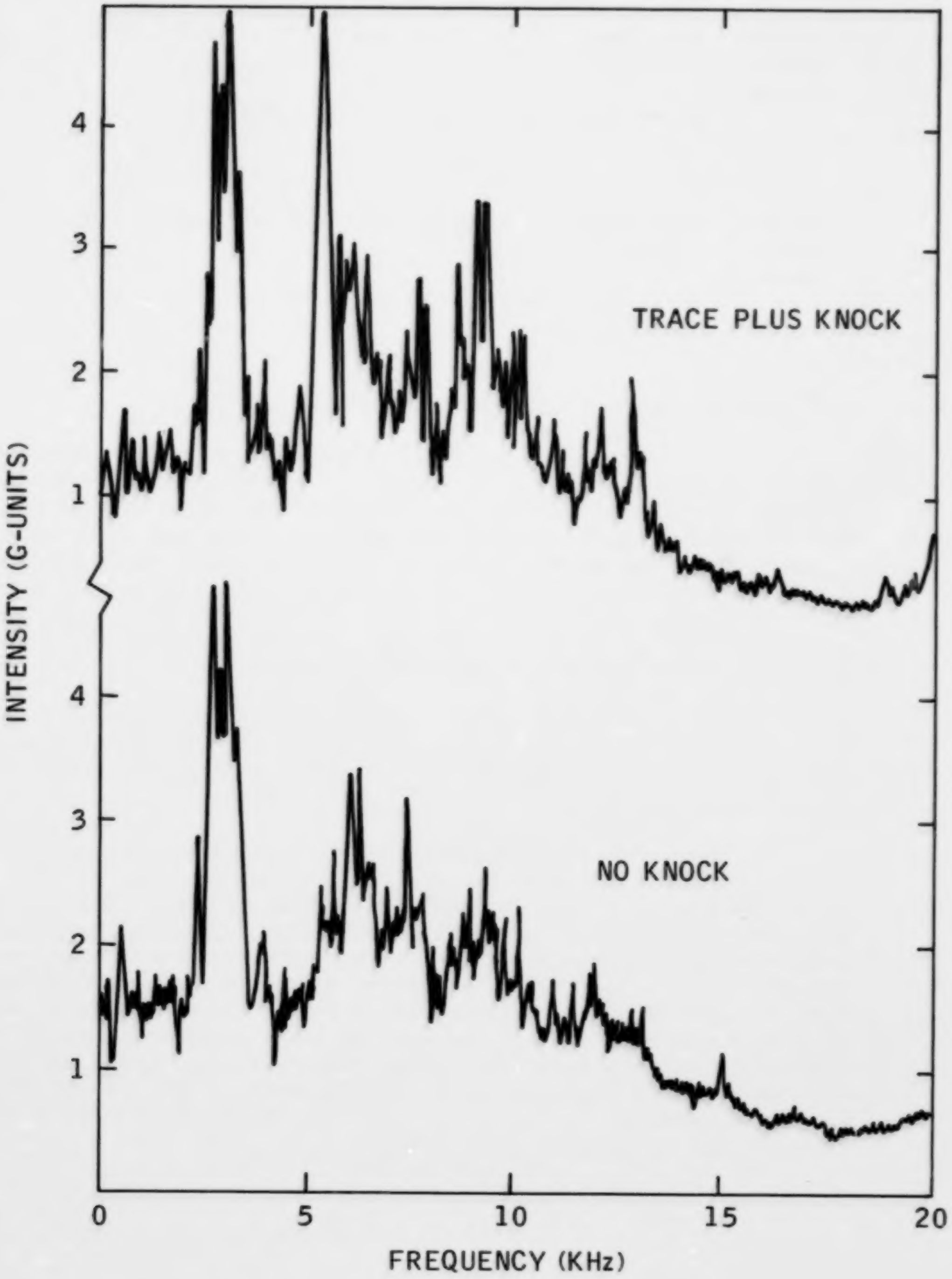


Table 7-4 Frequency and Intensity of the Accelerometer Signals for 2.3 Liter Engine

		Ratio of Knocking to No-Knock Signal Areas					
	Position	5.4	9.4	10.0	11.0	13.5	kHz
Steady State 50 mph	Rear Head (axial)	3.4	2.1	—	2.5	4.0	
	Right Rear Head (transverse)	2.1	--	3.9	--	--	
30-60 mph Accel.	Rear Head (axial)	2.8	7.7	--	4.6	5.0	
	Right Rear Head (transverse)	3.2	--	10.3	--	--	

7.2 FORD 2.8 LITER V-6 MUSTANG-II ENGINE

A 2.8 liter V-6 engine was also mounted on an engine dynamometer stand and tested to determine its knock frequency. The cycle follower was programmed with the same road load curve as used in the case of the 2.3 liter engine. The inertia loading was increased slightly since the engine typically went into a Mustang-II which is somewhat heavier than the Pinto. Six accelerometers were mounted as shown in the schematic in Figure 7-9. Two accelerometers were mounted on the intake manifold, 2 on front head bolts transverse to the crankshaft, and the other 2 were mounted in axial positions on the rear of the heads.

As in the case of the 2.3 liter engine, acceleration tests (from 40 to 70 mph at WOT), and steady state tests at 1600 rpm (∿35 mph) and 2550 rpm (∿55 mph). These data are compiled in Appendix F with only a summary presented here.

Representative frequency analyses obtained during 40 to 70 mph accelerations are given in Figures 7-10 through 7-15 for all six accelerometer locations. It can be seen from looking at these frequency-intensity plots that the range of frequencies which can be attributed to knock is much wider than that seen either in the 350 CID V-8 or the 2.3 liter 4-cylinder engine. In fact, when trying to assign peaks corresponding to knock by comparing the no-knock and very light knock intensity plots, 20-30 peaks could be found. Since many of these peaks are closely spaced together, frequency intervals rather than individual peaks were used for the comparison of knocking and no-knock spectra. The ratio of areas between the knock and no-knock cases for the intervals 5 to 8, 8 to 11, and 12 to 15 kHz is given in Table 7-5.

FIGURE 7-9

LOCATION OF ACCELEROMETERS ON
FORD 2.8 LITER V6 ENGINE (TOP VIEW)

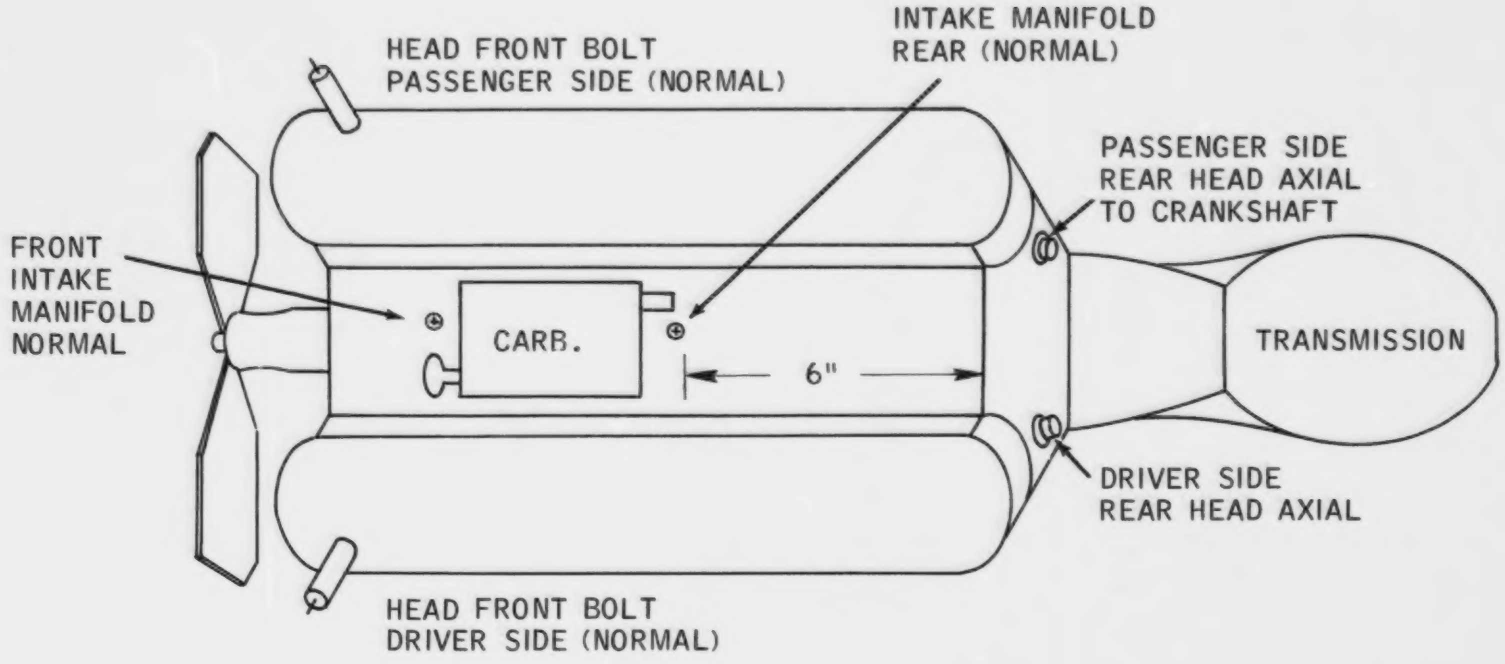

HEAD FRONT BOLT
PASSENGER SIDE (NORMAL)
INTAKE MANIFOLD
REAR (NORMAL)
PASSENGER SIDE
REAR HEAD AXIAL
TO CRANKSHAFT
FRONT
INTAKE
MANIFOLD
NORMAL
CARB.
6"
TRANSMISSION
DRIVER SIDE
REAR HEAD AXIAL
HEAD FRONT BOLT
DRIVER SIDE (NORMAL)

FIGURE 7-10

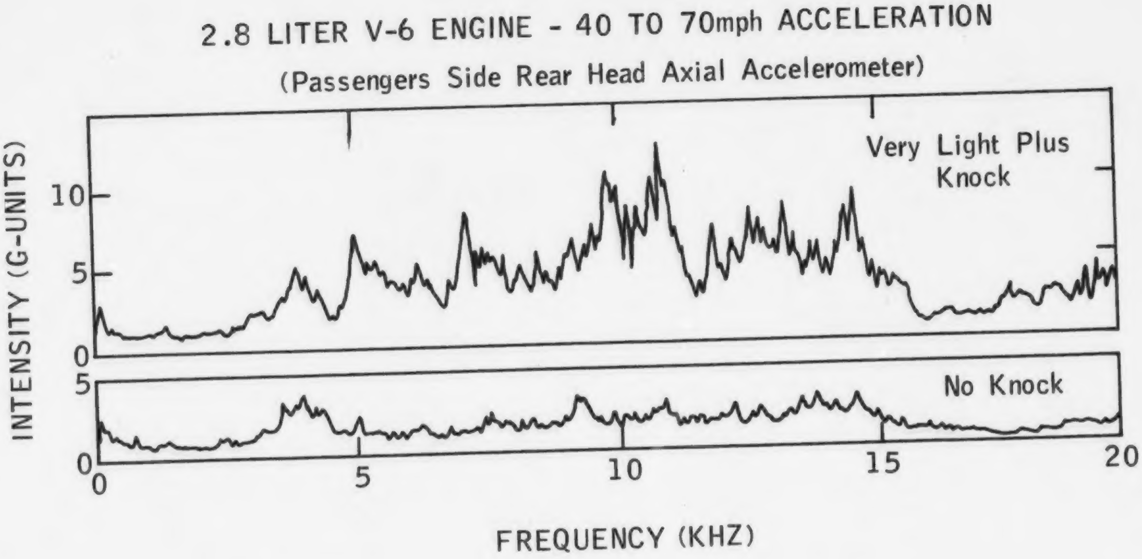
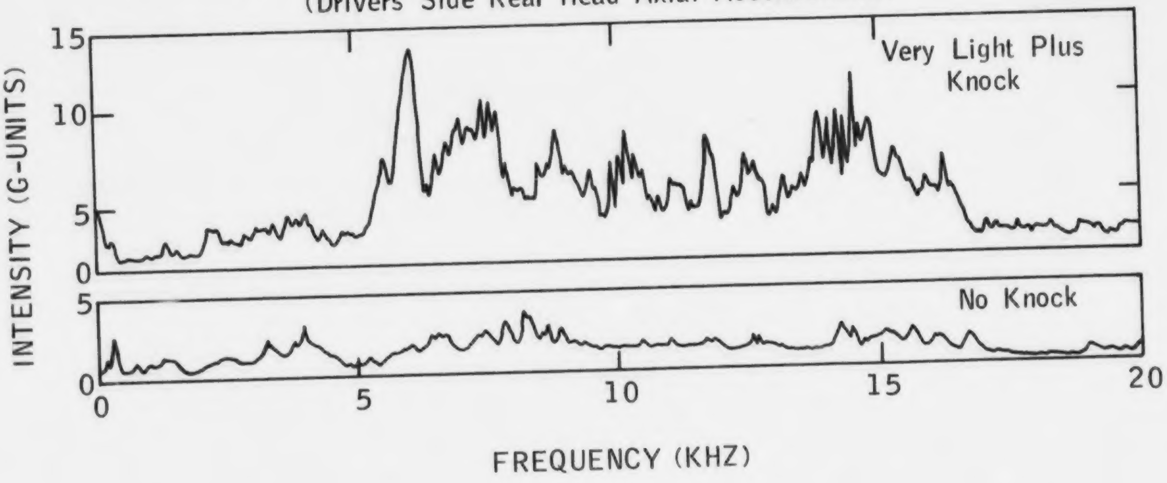

2.8 LITER V-6 ENGINE - 40 TO 70mph ACCELERATION
(Passengers Side Rear Head Axial Accelerometer)
INTENSITY (G-UNITS)
10
5
0
5
0
Very Light Plus Knock
No Knock
0
5
10
15
20
FREQUENCY (KHZ)

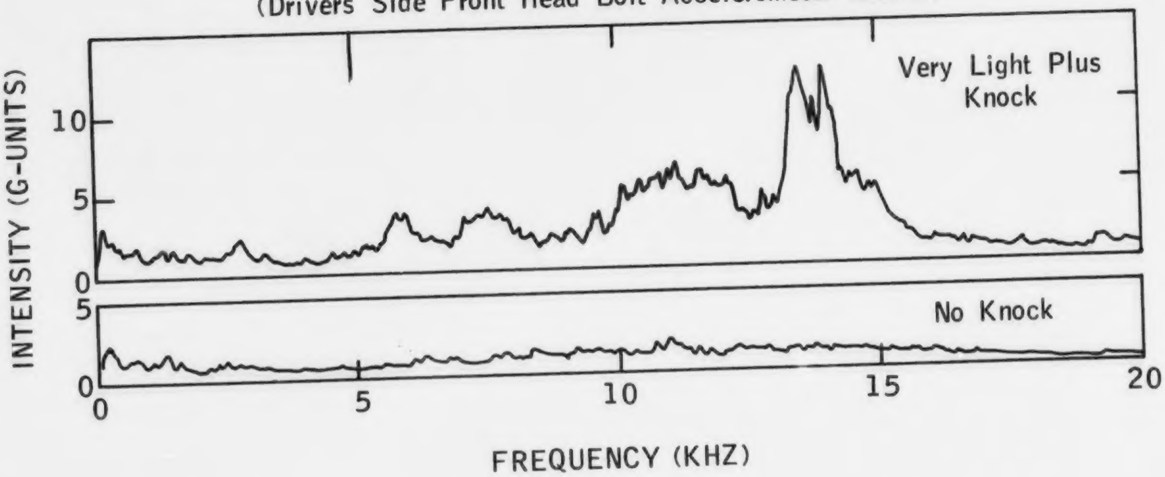
FIGURE 7-11



2.8 LITER V-6 ENGINE - 40 TO 70mph ACCELERATION

(Drivers Side Rear Head Axial Accelerometer)

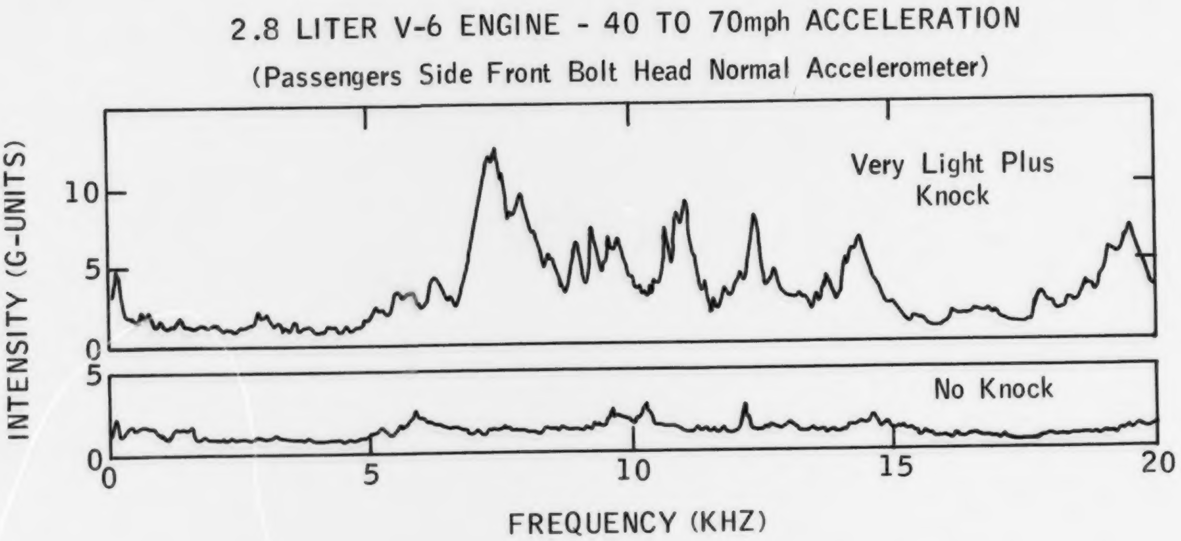
FIGURE 7-12



2.8 LITER V-6 ENGINE - 40 TO 70mph ACCELERATION

(Drivers Side Front Head Bolt Accelerometer Normal)

FIGURE 7-13



2.8 LITER V-6 ENGINE - 40 TO 70mph ACCELERATION

(Passengers Side Front Bolt Head Normal Accelerometer)

FIGURE 7-14

2.8 LITER V-6 ENGINE - 40 TO 70mph ACCELERATION

(Front Intake Manifold (Normal) Accelerometer)

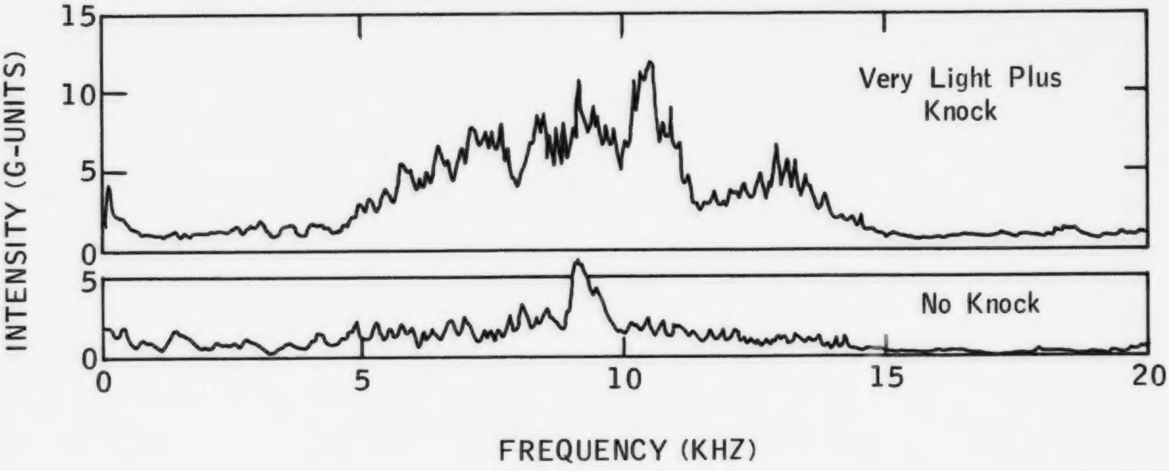
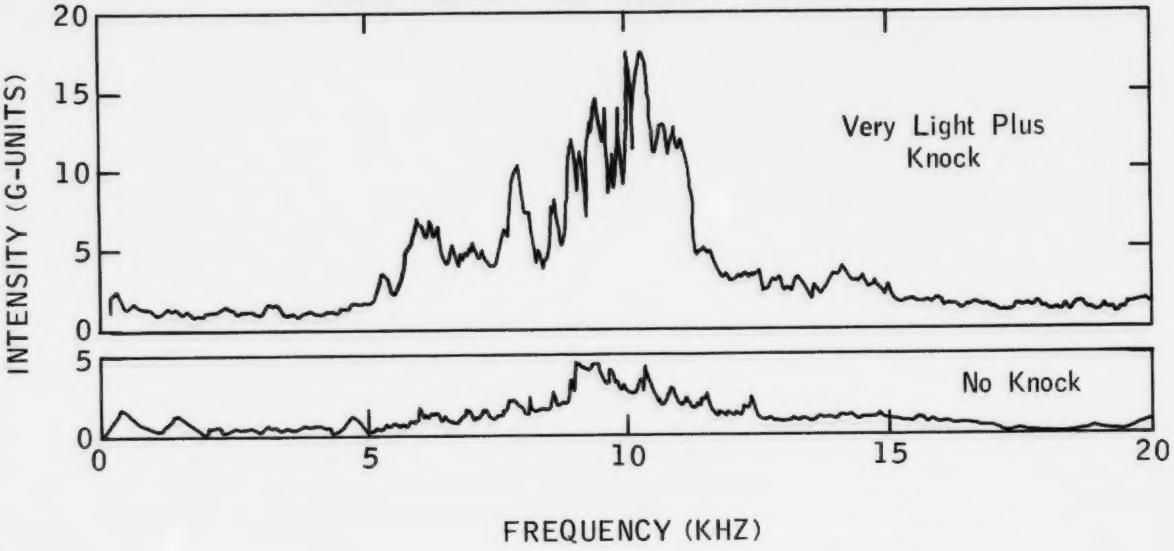


FIGURE 7-15



2.8 LITER V-6 ENGINE - 40 TO 70mph ACCELERATION

(Intake Manifold Rear (Normal) Accelerometer)

Table 7-5 Summary of Frequency Analysis of Ford 2.8 Liter V-6 Engine

Accelerometer	Signal/Noise (Area) Ratio 5 to 8 kHz	 8 to 11 kHz	 12 to 15 kHz
Rear Head - Passenger Side	7.7	2.9	2.8
Rear Head - Driver Side	5.0	2.5	4.4
Front Head Bolt - Driver Side	3.1	2.4	7.9
Front Head Bolt - Passenger Side	3.1	1.6	2.6
Intake Manifold - Front	2.6	3.5	2.5
Intake Manifold - Rear	3.8	3.5	2.5

The following conclusions can be drawn from the data.

1. Wider frequency intervals rather than sharp peaks appear to be characteristic of this 2.8 liter V-6 engine. This would suggest that if a knock sensor actuated control system were to be developed, a wider filter bandwidth might be considered to take advantage of these relatively wide frequency windows.

2. The rear head (axial) accelerometer locations both on the driver and passenger side gave very good signal to noise ratios for the 5 to 8 kHz interval. This result agrees well with our findings on the 350 CID V-8 engine, where the rear head axial positions showed the best signal/noise ratios for a relatively well-defined 5.3 kHz peak.

3. A high signal/noise ratio peak located in the 12 to 15 kHz interval was found in the front head bolt-driver side frequency analysis.

The results of the 2.8 liter V-6 engine's frequency analyses suggest that the rear head axial location may be the best for optimizing signal/noise ratio for this engine. This was also found to be very clearly the case for the 350 CID V-8 engine. In the case of 2.3 liter 4-cylinder engine, where background engine noise is a problem, the choice between the axial and transverse locations on the cylinder head was not that obvious. However, again it was clear that accelerometers located on the cylinder heads gave better signal/noise ratio than those either mounted on the block or the intake manifold.

Nothing found on the frequency analysis results would cause concern regarding the building of a knock sensor-actuated spark control system for these engines. Frequency intervals with good signal/noise ratios can be found for both the 2.3 and 2.8 liter engines. After that, it is simply a matter of designing and building a filter to match the intervals chosen with some broadening added to allow for engine-to-engine variations. Thus this type of approach would appear to be feasible in all three engines examined.

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APPENDIX A

FREQUENCY ANALYSIS OF ACCELEROMETER SIGNALS FROM 350 CID CHEVROLET V-8 ENGINE

A-1 through A-84	Test #1 Spare Engine
A-85 through A-122	Test #2 Engine from Vehicle

TEST #1

SPARE 350 CID ENGINE

Accelerometer No.	Location	
1	Left Front Cylinder Head	Transverse
2	Left Rear Cylinder Head	Transverse
3	Rear Intake Manifold	Transverse
4	Front Intake Manifold	Transverse
5	Right Front Cylinder Head	Transverse
6	Right Rear Cylinder Head	Axial

SUMMARY OF SPECTROGRAM RESULTS

Plot No.	Accelerometer Number	Test	Plot Axis	Amp. Scale	Rated Knock Level	Max. Response	Comments
1	1 to 6	Steady State	Freq & Time	.5g/major div.	Trace Plus		
1 - 1	1	Fuel Change	Freq & Time	.5g/major div.	Trace Plus	.4g max	poor response
1 - 2	2	Fuel Change	Freq & Time	.5g/major div.	Trace Plus	.6g max	poor response
1 - 3	3	Fuel Change	Freq & Time	.5g/major div.	Trace Plus	.75 max	med response
1 - 4	4	Fuel Change	Freq & Time	.5g/major div.	Trace Plus	.3g max	poor response
1 - 5	5	Fuel Change	Freq & Time	.5g/major div.	Trace Plus		no response
1 - 6	6	Fuel Change	Freq & Time	.5g/major div.	Trace Plus	1.8g max	good response
2 - 1	1	Steady State	Freq & Time	.5g/major div.	Trace		no response
2 - 2	2	Steady State	Freq & Time	.5g/major div.	Trace		no response
2 - 3	3	Steady State	Freq & Time	.5g/major div.	Trace		no response
2 - 4	4	Steady State	Freq & Time	.5g/major div.	Trace		no response
2 - 5	5	Steady State	Freq & Time	.5g/major div.	Trace		no response
2 - 6	6	Steady State	Freq & Time	.5g/major div.	Trace	1.0 max	med response
3 - 1	1	Steady State	Freq & Time	.5g/major div.	None		no response
3 - 2	2	Steady State	Freq & Time	.5g/major div.	None		no response
3 - 3	3	Steady State	Freq & Time	.5g/major div.	None		no response
3 - 4	4	Steady State	Freq & Time	.5g/major div.	None		no response
3 - 5	5	Steady State	Freq & Time	.5g/major div.	None		no response

Plot No.	Accelerometer Number	Test	Plot Axis	Amp. Scale	Rated Knock Level	Max. Response	Comments
3 - 6	6	Steady State	Freq & Time	.5g/major div.	None		no response
4 - 1	1	Steady State	Freq & Time	.5g/major div.	None		no response
4 - 2	2	Steady State	Freq & Time	.5g/major div.	None		no response
4 - 3	3	Steady State	Freq & Time	.5g/major div.	None		no response
4 - 4	4	Steady State	Freq & Time	.5g/major div.	None		no response
4 - 5	5	Steady State	Freq & Time	.5g/major div.	None		no response
4 - 6	6	Steady State	Freq & Time	.5g/major div.	None		no response
5 - 1	1	Steady State	Freq & Time	.5g/major div.	Very light plus		no response
5 - 2	2	Steady State	Freq & Time	.5g/major div.	Very light plus		no response
5 - 3	3	Steady State	Freq & Time	.5g/major div.	Very light plus		no response
5 - 4	4	Steady State	Freq & Time	.5g/major div.	Very light plus		no response
5 - 5	5	Steady State	Freq & Time	.5g/major div.	Very light plus		no response
5 - 6	6	Steady State	Freq & Time	.5g/major div.	Very lt. plus	2g max	good response
6 - 4	4	Fuel Change	Freq & Time	.5g/major div.	Very light		no response
6 - 5	5	Fuel Change	Freq & Time	.5g/major div.	Very light		no response
6 - 6	6	Fuel Change	Freq & Time	.5g/major div.	Very light	1.2g max	med response
7 - 1	1	Acceleration	Freq & RPM	1g/major div.	All levels	1.6g max	med response
7 - 2	2	Acceleration	Freq & RPM	1g/major div.	All levels	2.5g max	med response
7 - 3	3	Acceleration	Freq & RPM	1g/major div.	All levels	2g max	med response

Plot No.	Accelerometer Number	Test	Plot Axis	Amp. Scale	Rated Knock Level	Max. Response	Comments
7 - 4	4	Acceleration	Freq & RPM	lg/major div.	All levels		no response
7 - 5	5	Acceleration	Freq & RPM	lg/major div.	All levels		no response
7 - 6	6	Acceleration	Freq & RPM	lg/major div.	All levels	5g max	good response
8 - 1	1	Acceleration	Freq & RPM	lg/major div.	All levels		no response
8 - 2	2	Acceleration	Freq & RPM	lg/major div.	All levels	2.5g max	med response
8 - 3	3	Acceleration	Freq & RPM	lg/major div.	All levels	2g max	med response
8 - 4	4	Acceleration	Freq & RPM	lg/major div.	All levels	1.5g max	poor response
8 - 5	5	Acceleration	Freq & RPM	lg/major div.	All levels	.6g max	poor response
8 - 6	6	Acceleration	Freq & RPM	lg/major div.	All levels	5g max	good response
9 - 1	1	Acceleration	Freq & RPM	lg/major div.	None		no response
9 - 2	2	Acceleration	Freq & RPM	lg/major div.	None		no response
9 - 3	3	Acceleration	Freq & RPM	lg/major div.	None		no response
9 - 4	4	Acceleration	Freq & RPM	lg/major div.	None		no response
9 - 5	5	Acceleration	Freq & RPM	lg/major div.	None		no response
9 - 6	6	Acceleration	Freq & RPM	lg/major div.	None		no response
10- 1	1	Acceleration	Freq & RPM	lg/major div.	Very light	.7g max	poor response
10- 2	2	Acceleration	Freq & RPM	lg/major div.	Very light	2.5g max	med response
10- 3	3	Acceleration	Freq & RPM	lg/major div.	Very light		no response
10- 4	4	Acceleration	Freq & RPM	lg/major div.	Very light		no response

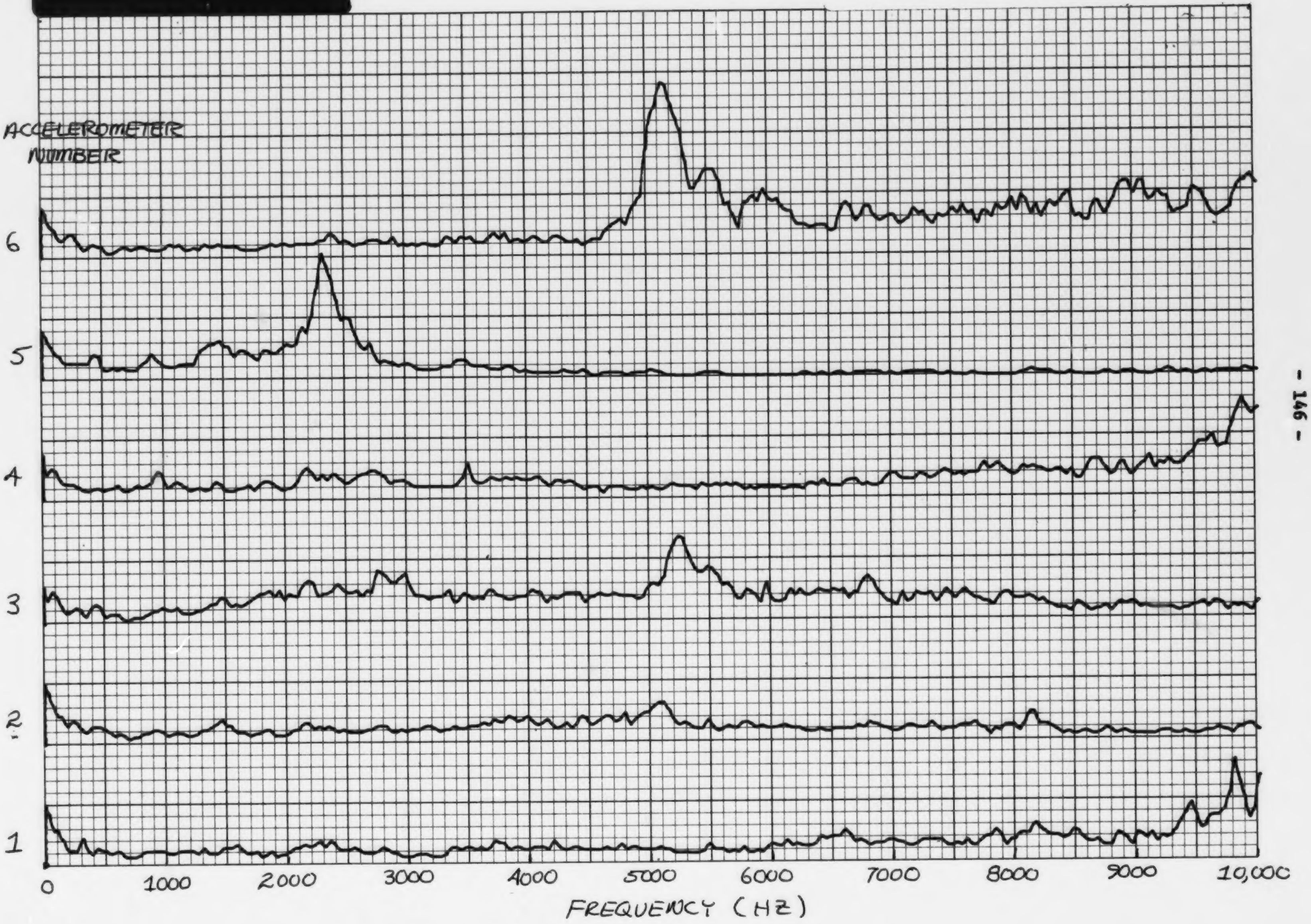
Plot No.	Accelerometer Number	Test	Plot Axis	Amp. Scale	Rated Knock Level	Max. Response	Comments
10- 5	5	Acceleration	Freq & RPM	1g/major div.	Very light		no response
10- 6	6	Acceleration	Freq & RPM	1g/major div.	Very light	3g max	good response
11- 1	1	Acceleration	Freq & RPM	1g/major div.	None		no response
11- 2	2	Acceleration	Freq & RPM	1g/major div.	None		no response
11- 3	3	Acceleration	Freq & RPM	1g/major div.	None		no response
11- 4	4	Acceleration	Freq & RPM	1g/major div.	None		no response
11- 5	5	Acceleration	Freq & RPM	1g/major div.	None		no response
11- 6	6	Acceleration	Freq & RPM	1g/major div.	None		no response
12- 1	1	Steady State	Freq & Time	.5g/major div.	Trace		no response
12- 2	2	Steady State	Freq & Time	.5g/major div.	Trace		no response
12- 3	3	Steady State	Freq & Time	.5g/major div.	Trace		no response
12- 4	4	Steady State	Freq & Time	.5g/major div.	Trace		no response
12- 5	5	Steady State	Freq & Time	.5g/major div.	Trace		no response
12- 6	6	Steady State	Freq & Time	.5g/major div.	Trace	1.2g max	med response
13- 1	1	Steady State	Freq & Time	.5g/major div.	None		no response
13- 2	2	Steady State	Freq & Time	.5g/major div.	None		no response
13- 3	3	Steady State	Freq & Time	.5g/major div.	None		no response
13- 4	4	Steady State	Freq & Time	.5g/major div.	None		no response
13- 5	5	Steady State	Freq & Time	.5g/major div.	None		no response
13- 6	6	Steady State	Freq & Time	.5g/major div.	None		no response

Plot No.	Accelerometer Number	Test	Plot Axis	Amp. Scale	Rated Knock Level	Max. Response	Comments
14- 1	1	Fuel Change	Freq & Time	.5g/major div.	Trace		no response
14- 6	6	Fuel Change	Freq & Time	.5g/major div.	Trace	1.5g max	good response

[redacted]

#1

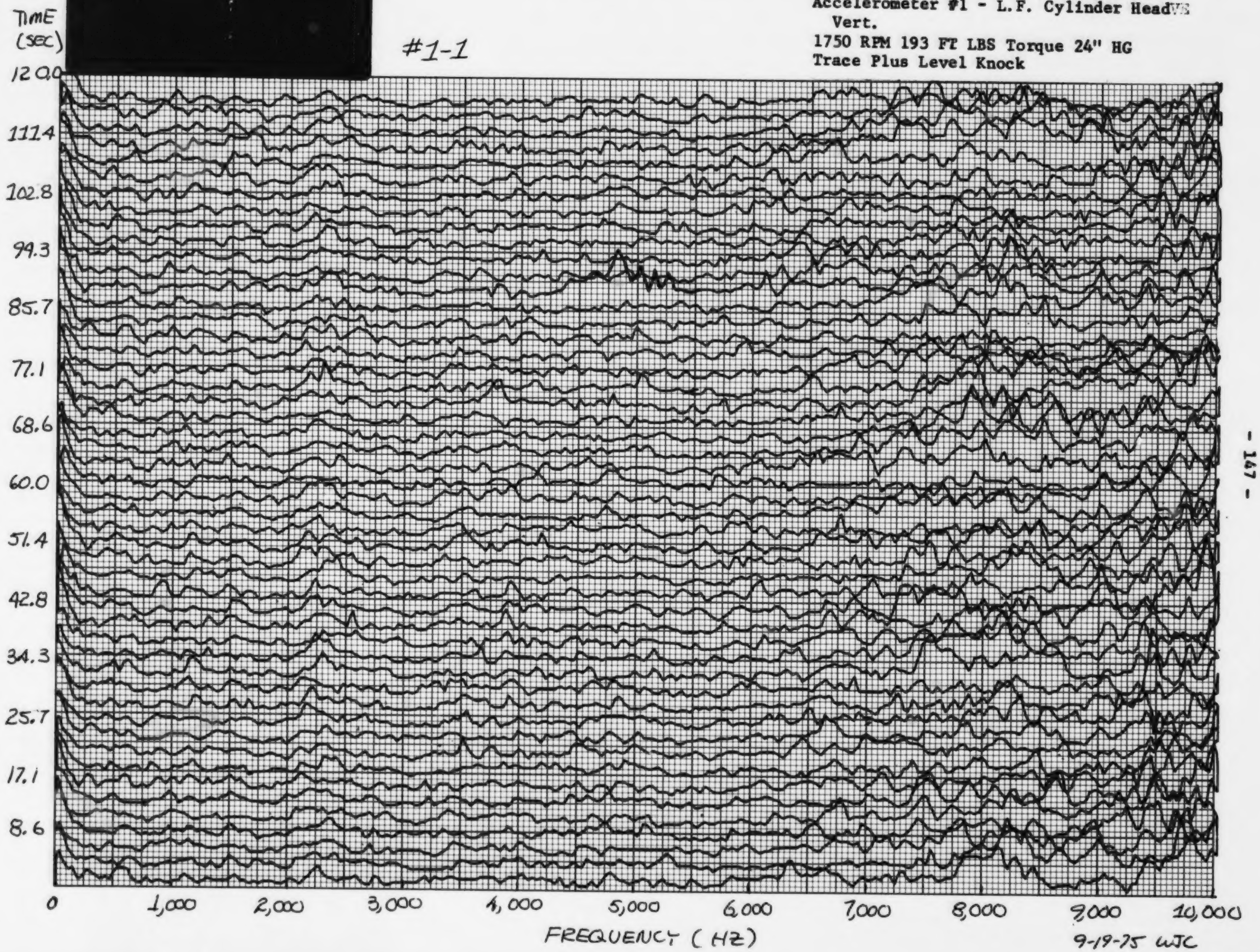
Typical Accelerometer Output
Steady State Test #1
1750 RPM 193 FT LBS TORQUE 25" HG
Trace Plus Level Knock



Fuel Change - House To 78 Octane Fuel
Accelerometer #1 - L.F. Cylinder Head
Vert.
1750 RPM 193 FT LBS Torque 24" HG
Trace Plus Level Knock

#1-1

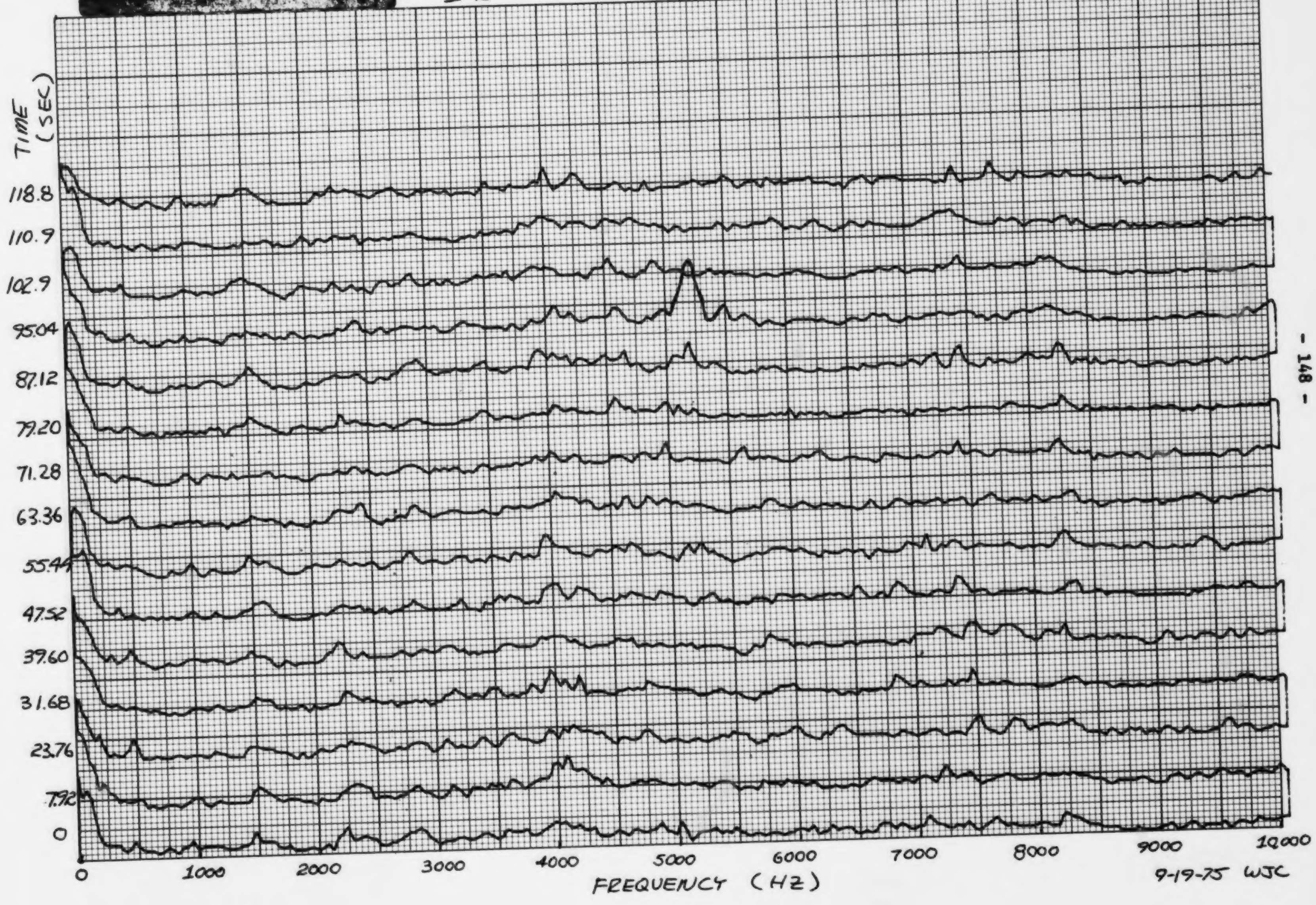
[redacted]



9-19-75 WJC

Fuel Change - House To 78 Octane Fuel
Accelerometer #2 - L.R. Cylinder Head
Vert.
1750 RPM 193 FT LBS Torque 24" HG
Trace Plus Level Knock

#1-2

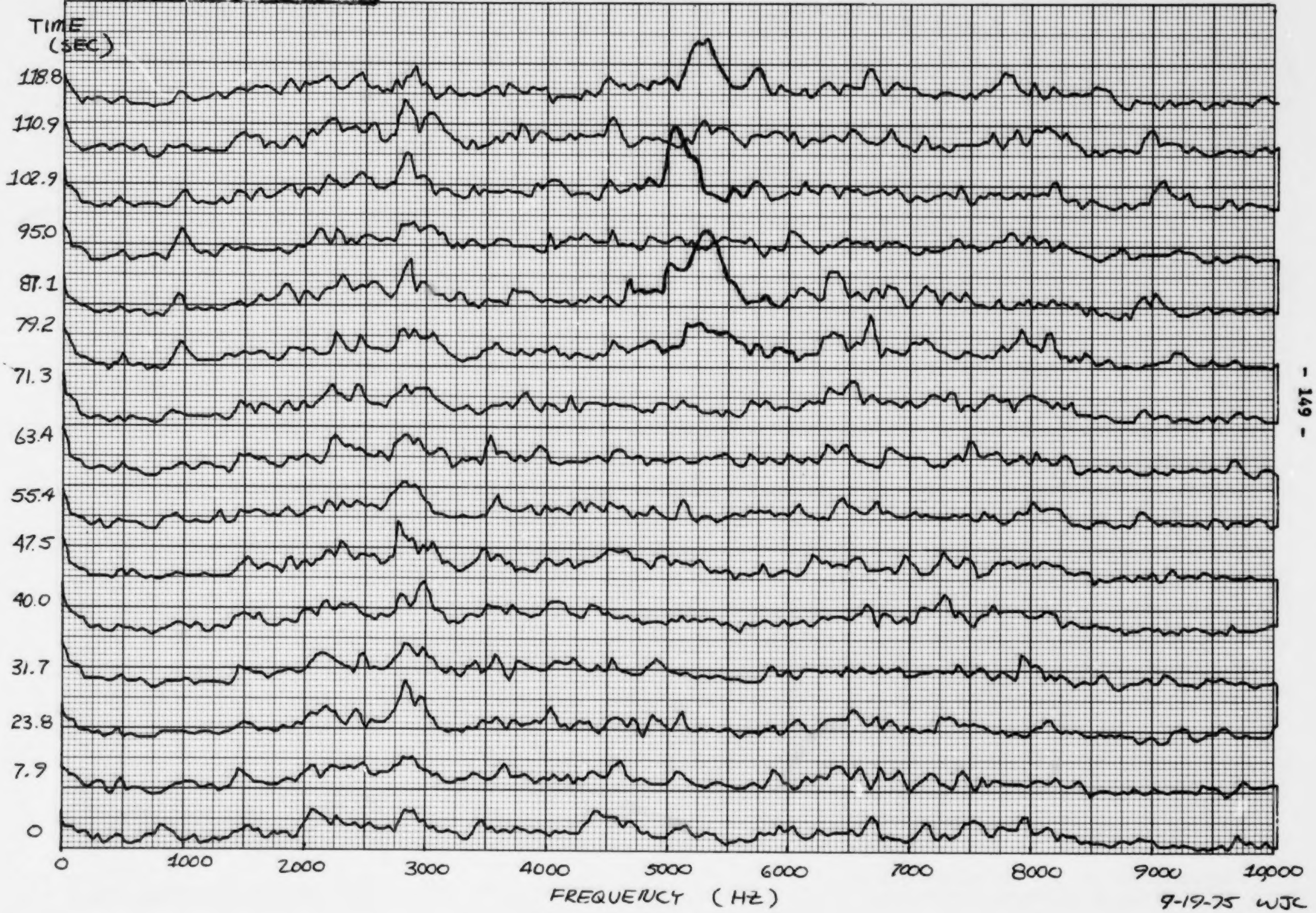


9-19-75 WJC

[illegible]

Fuel Change - House to 78 Octane Fuel
Accelerometer #3 - R. Intake Manifold
Vert.
1750 RPM 193 FT LBS Torque 24" HG
Trace Plus Level Knock

#1-3

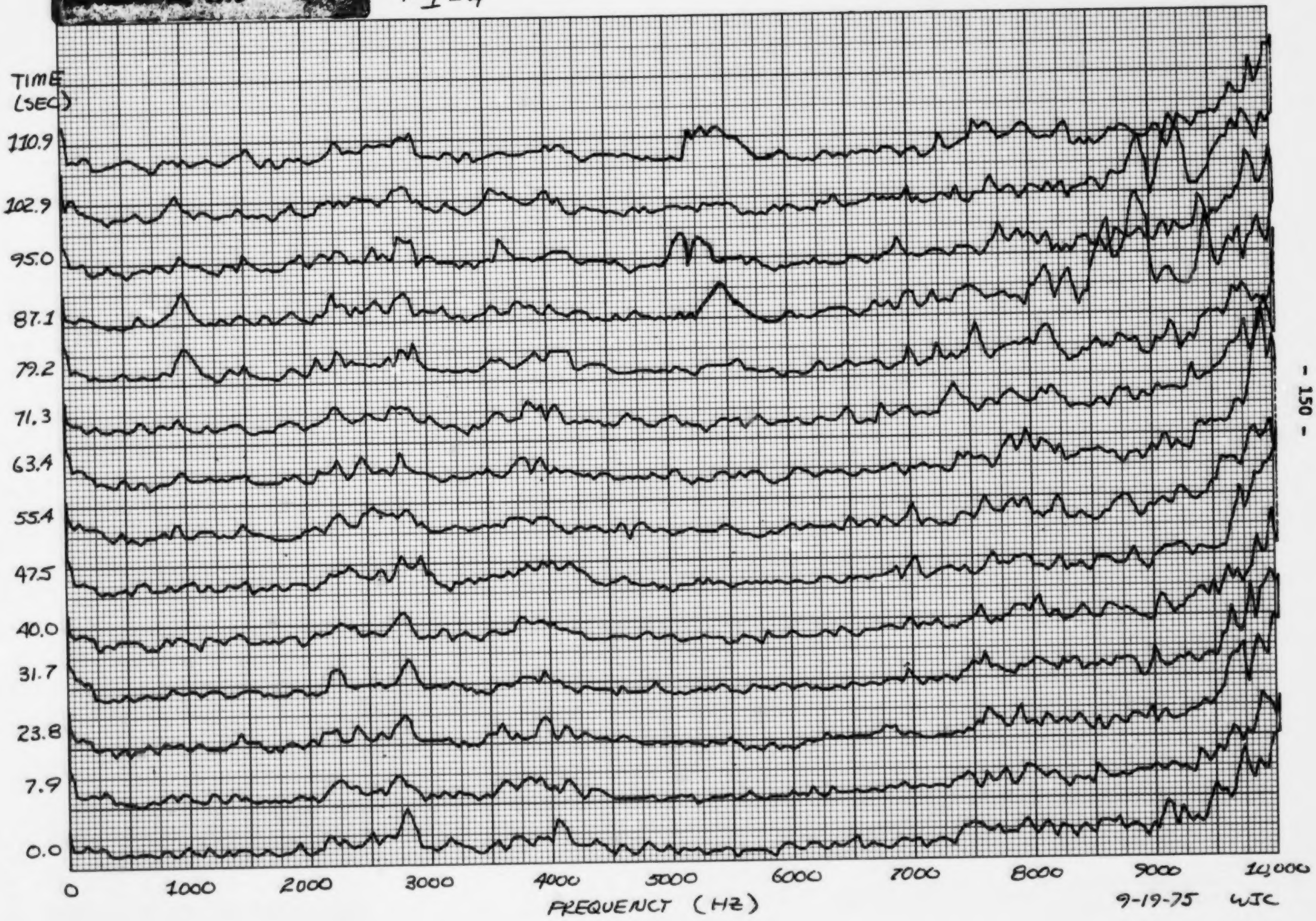


9-19-75 WJC

[illegible] Co. [illegible] 1975

Fuel Change - House To 78 Octane Fuel
Accelerometer #4 - F. Intake Manifold
  Vert.
1750 RPM 193 FT LBS Torque 24" HG
Trace Plus Level Knock

#1-4

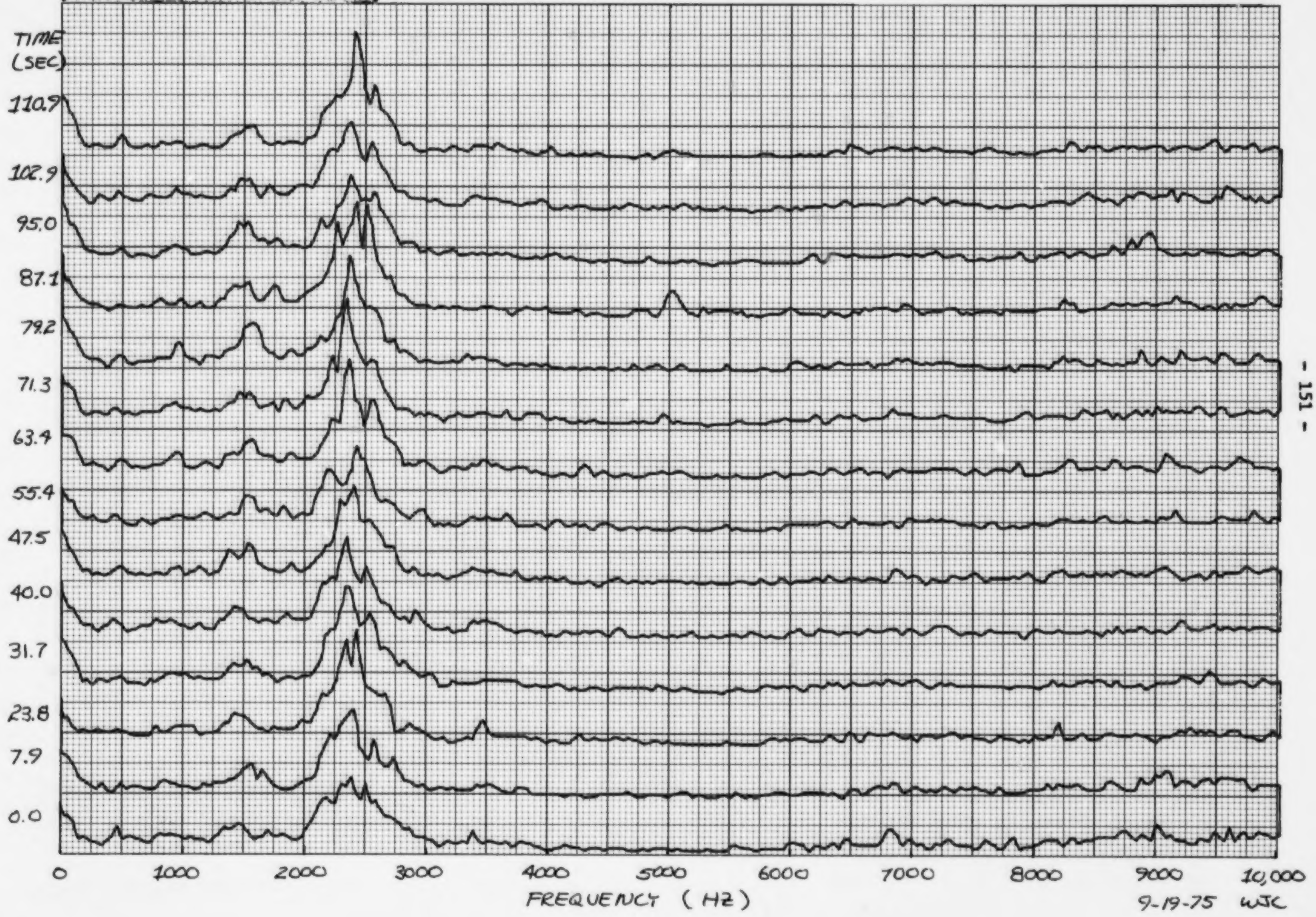


9-19-75 WJC

[illegible]
neering Co.
Knock Detection Test
Test Cell, ERC Building A
September 16, 1975

#1-5

Fuel Change - House To 78 Octane Fuel
Accelerometer #5 - R.F. Cylinder Head
Vert.
1750 RPM 193 FT LBS Torque 24" HG
Trace Plus Level Knock

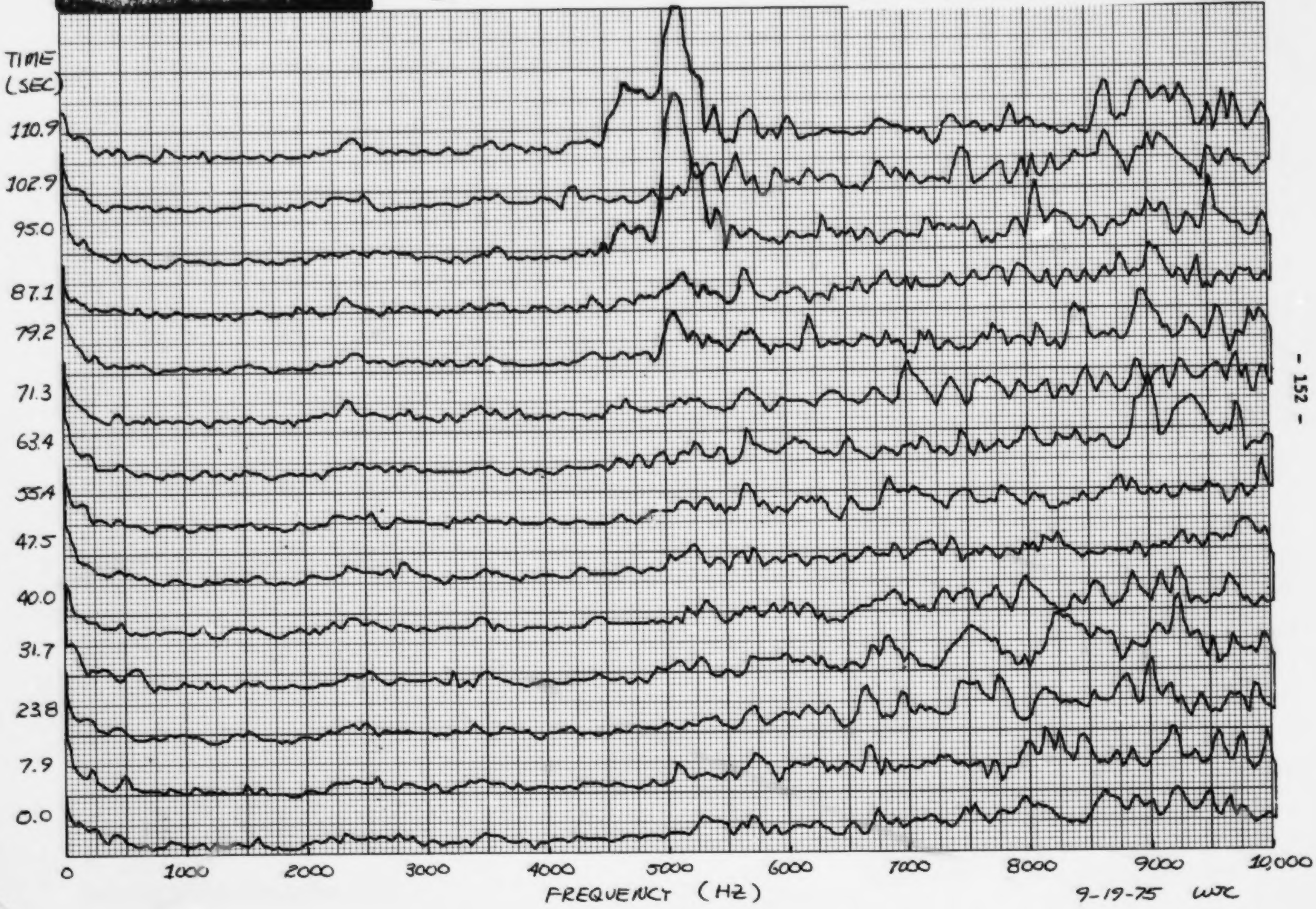


9-19-75 WJC

[illegible] Research And Engi-
neering Co.
[illegible] Detection Test
Test Cell, [illegible] Building 4
September [illegible], 1975

Fuel Change - House To 78 Octane Fuel
Accelerometer #6 - R.R. Cylinder Head
Hor.
1750 RPM 193 FT LBS Torque 24" HG
Trace Plus Level Knock

#1-6

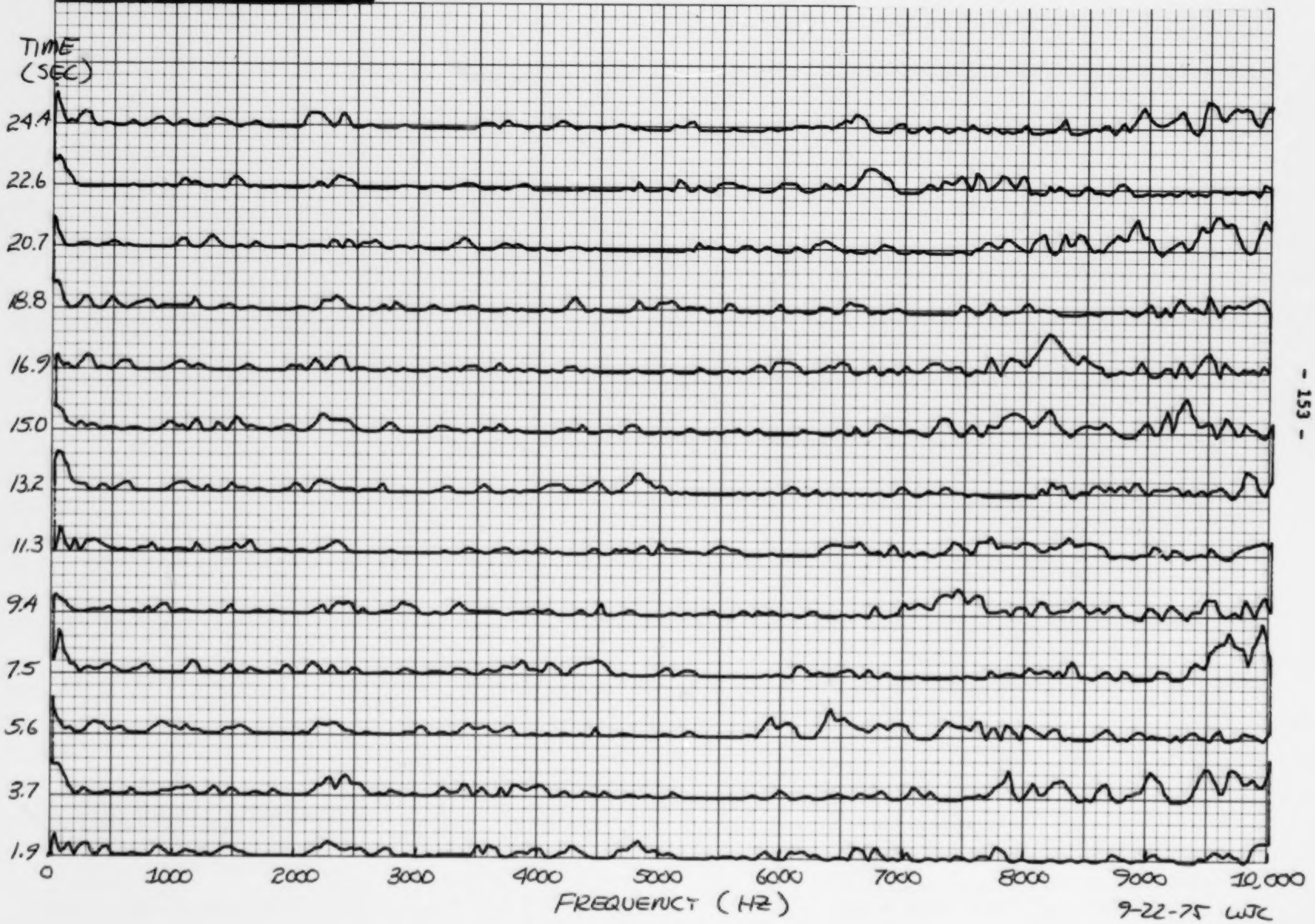


9-19-75 WJC

[illegible] Test
Test Cell, [illegible] Building [illegible]

#2-1

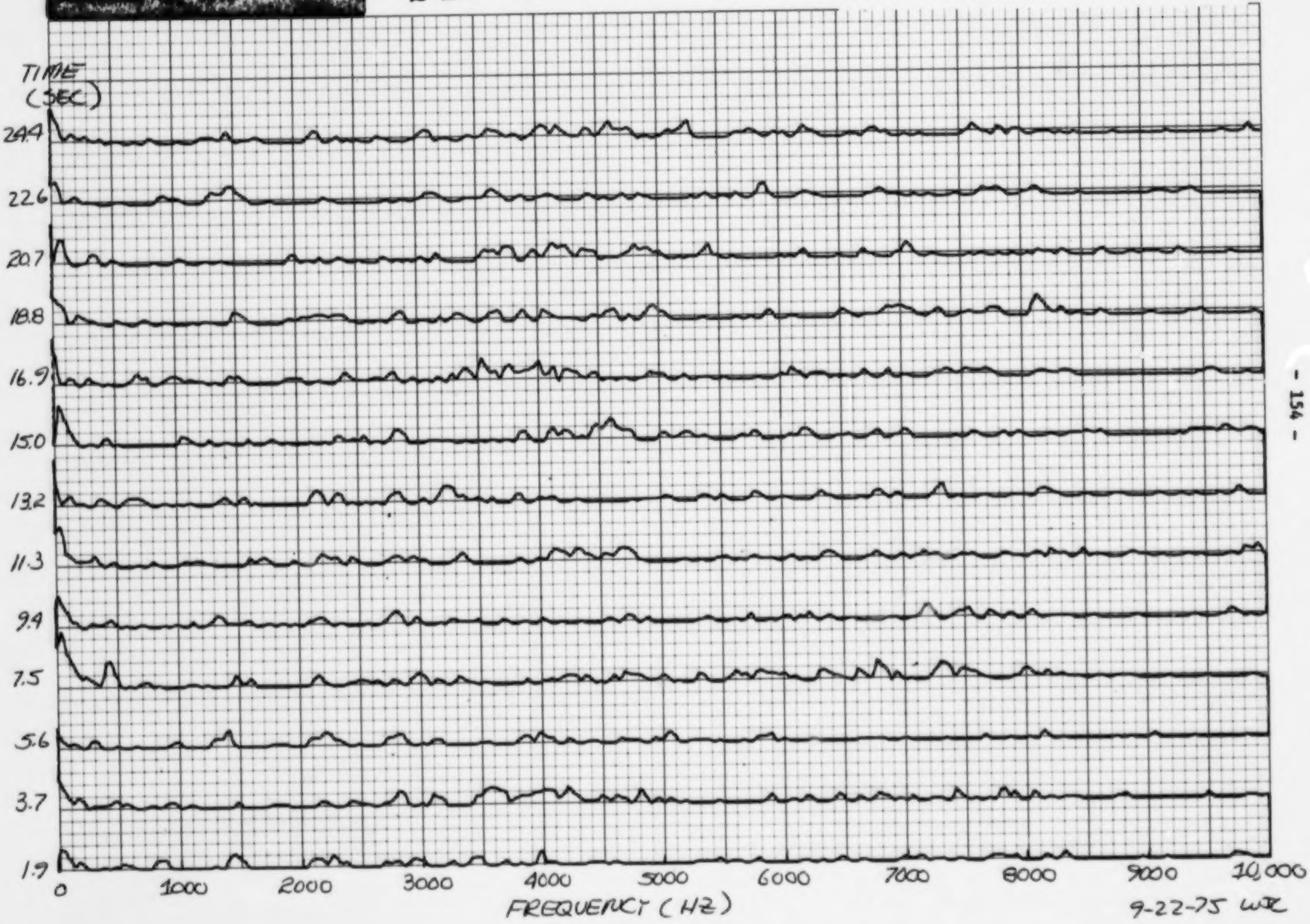
Steady State Test - 78 Octane Fuel
Accelerometer #1 - L.F. Cylinder Head
  Vert.
1750 RPM 193 FT LBS Torque 24" HG
Trace Level Knock



9-22-75 WJC

Steady State Test - 78 Octane Fuel
Accelerometer #2 - L.R. Cylinder Head
Vert.
1750 RPM 193 FT LBS Torque 24" HG
Trace Level Knock

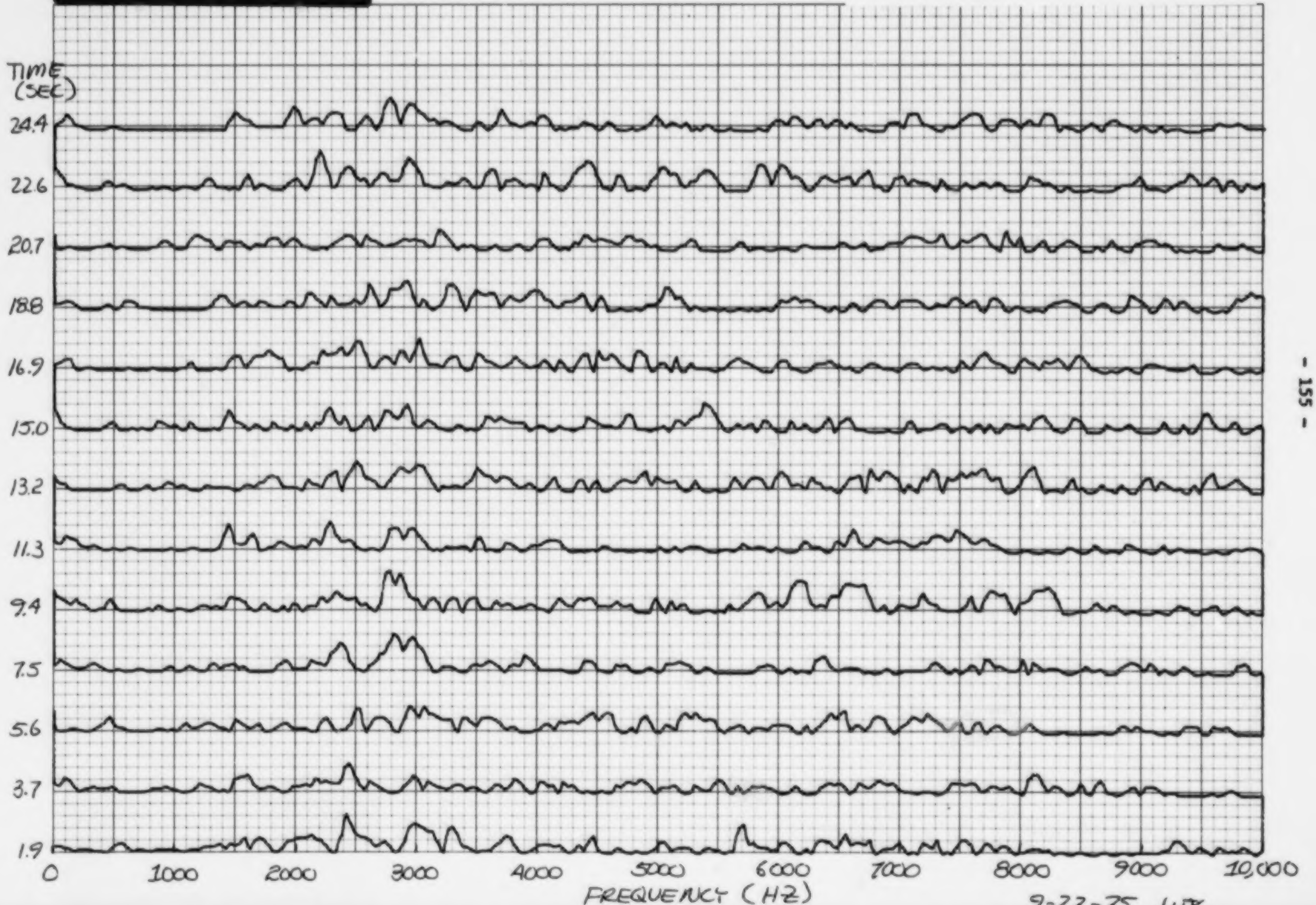
#2-2



9-22-75 WK

Steady State Test - 78 Octane Fuel
4Accelerometer #3 - R. Intake Manifold
Vert.
1750 RPM 193 FT LBS Torque 24" HG
Trace Level Knock

#2-3

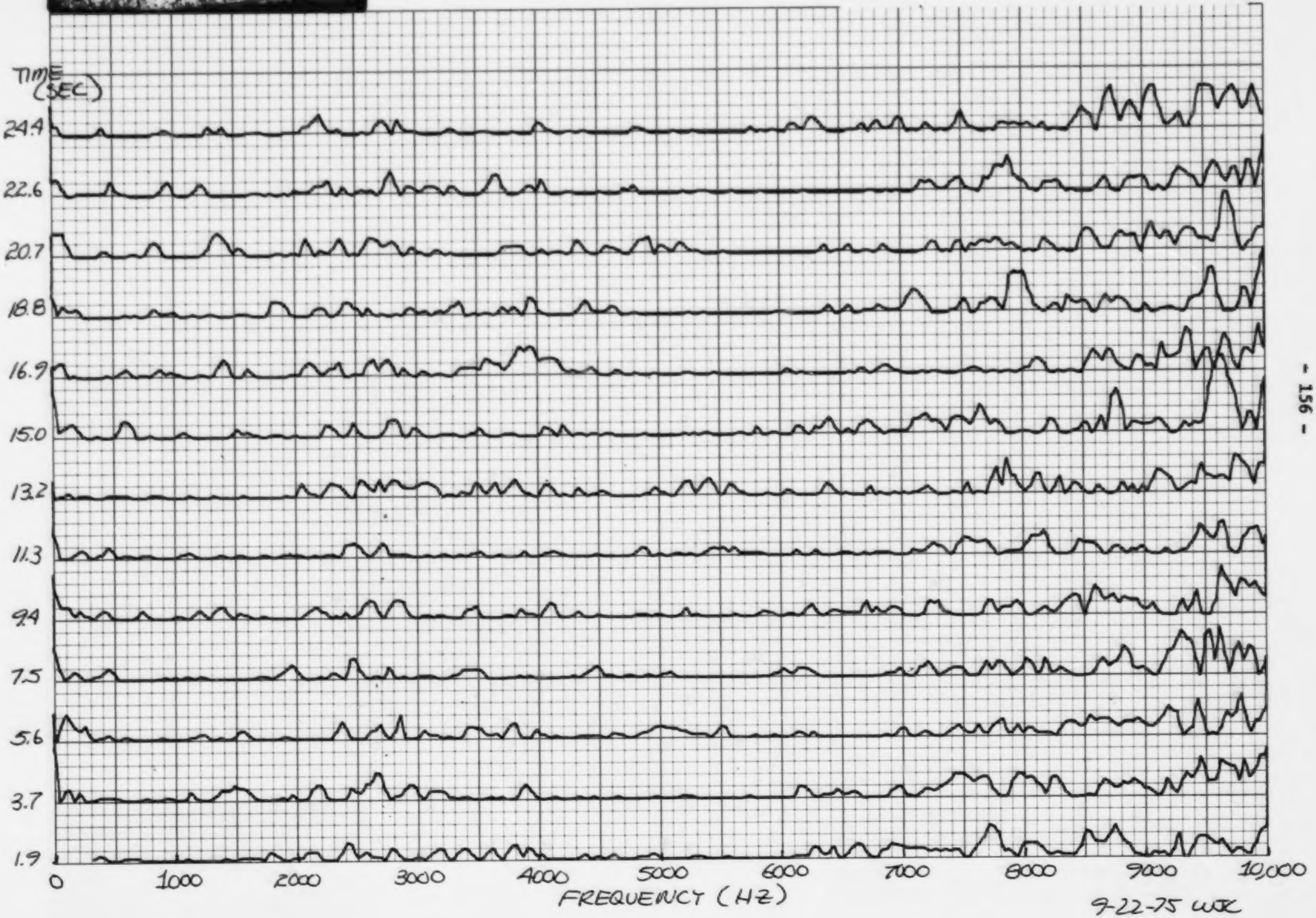


9-22-75 WJC

[illegible] Research And Engi-
neering Co.
[illegible] Detection Test
[illegible] Cell, [illegible]
[illegible] 1[illegible], [illegible]

#2-4

Steady State Test - 78 Octane Fuel
Accelerometer #4 - F. Intake Manifold
Vert.
1750 RPM 193 FT LBS Torque 24" HG
Trace Level Knock

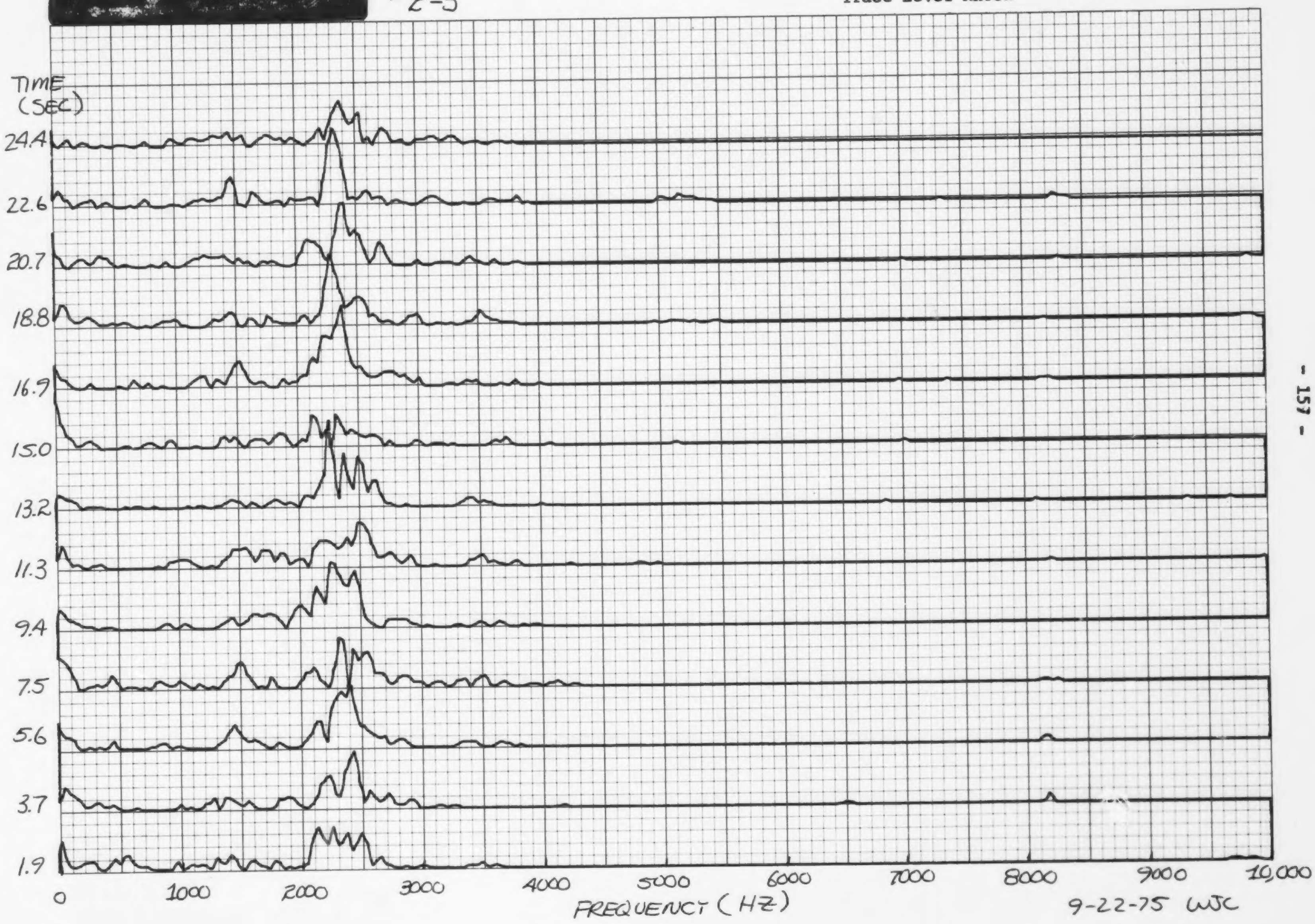


9-22-75 WJC

[illegible]

Steady State Test - 78 Octane Fuel
Accelerometer #5 - R.F. Cylinder Head
Vert.
1750 RPM 193 FT LBS Torque 24" HG
Trace Level Knock

#2-5

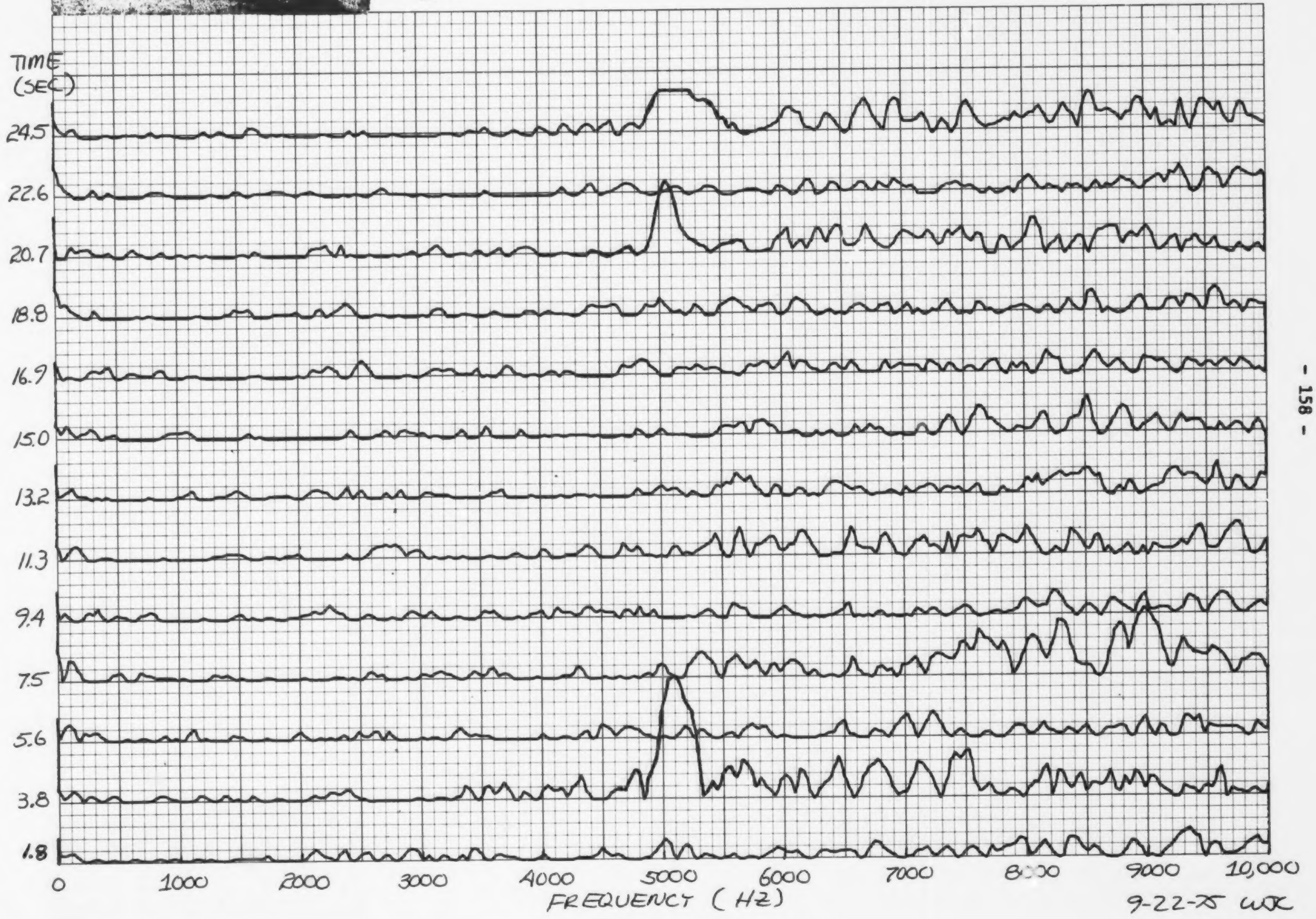


9-22-75 WJC

[illegible]

Steady State Test - 78 Octane Fuel
Accelerometer #6 - R.R. Cylinder Head
Vert.
1750 RPM 193 FT LBS Torque 24" HG
Trace Level Knock

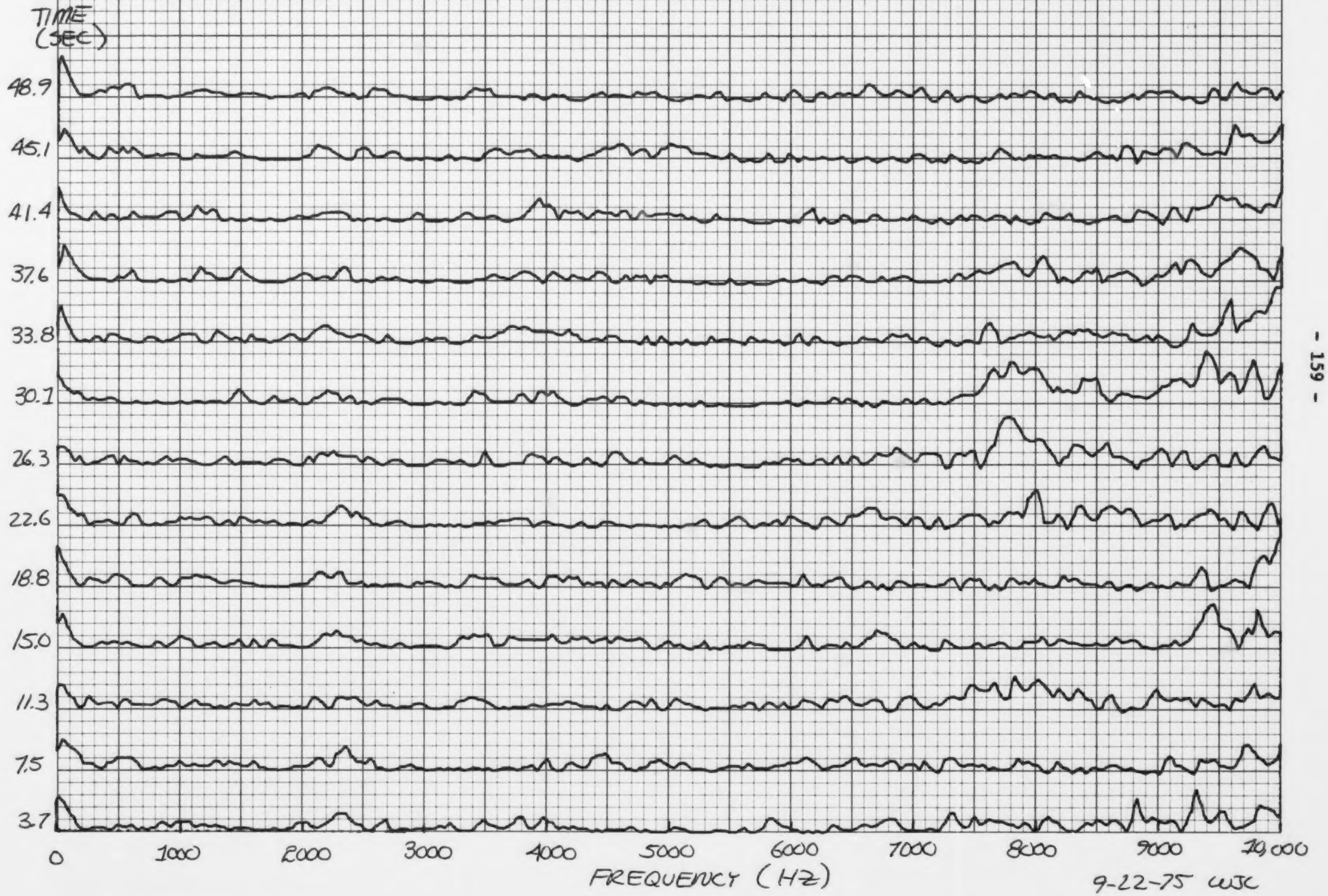
#2-6



9-22-75 WJC

#3-1

Steady State Test - 78 Octane Fuel
Accelerometer #1 - L.F. Cylinder Head
  Vert.
1750 RPM 170 FT LBS Torque 22" HG
No Knock - Slight Surface Ignition

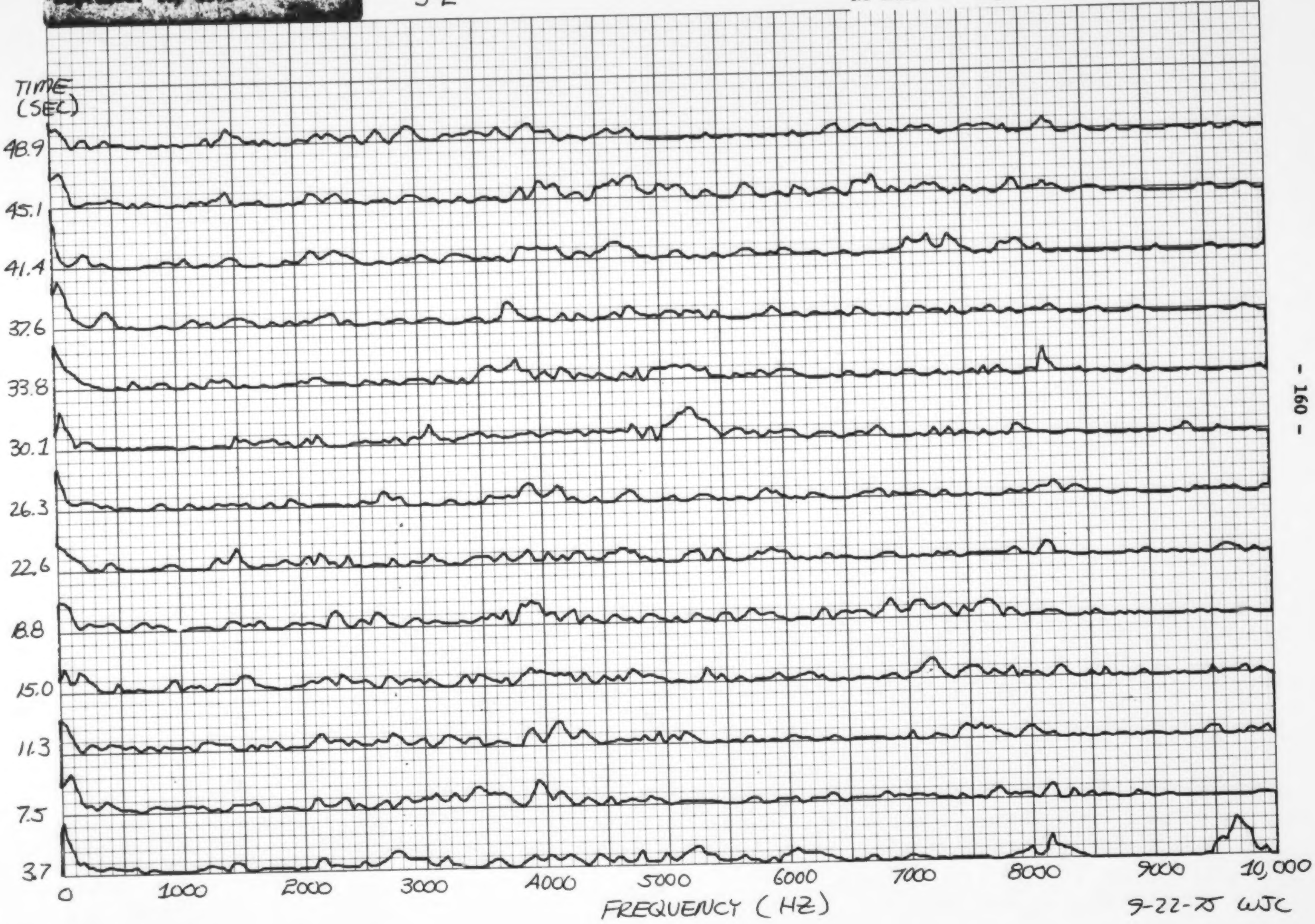


9-22-75 WJC

[illegible] Research and Engi-
neering Co.
Knock Detection Test
Test Cell, [illegible] Building 4
September 16, 1975

#3-2

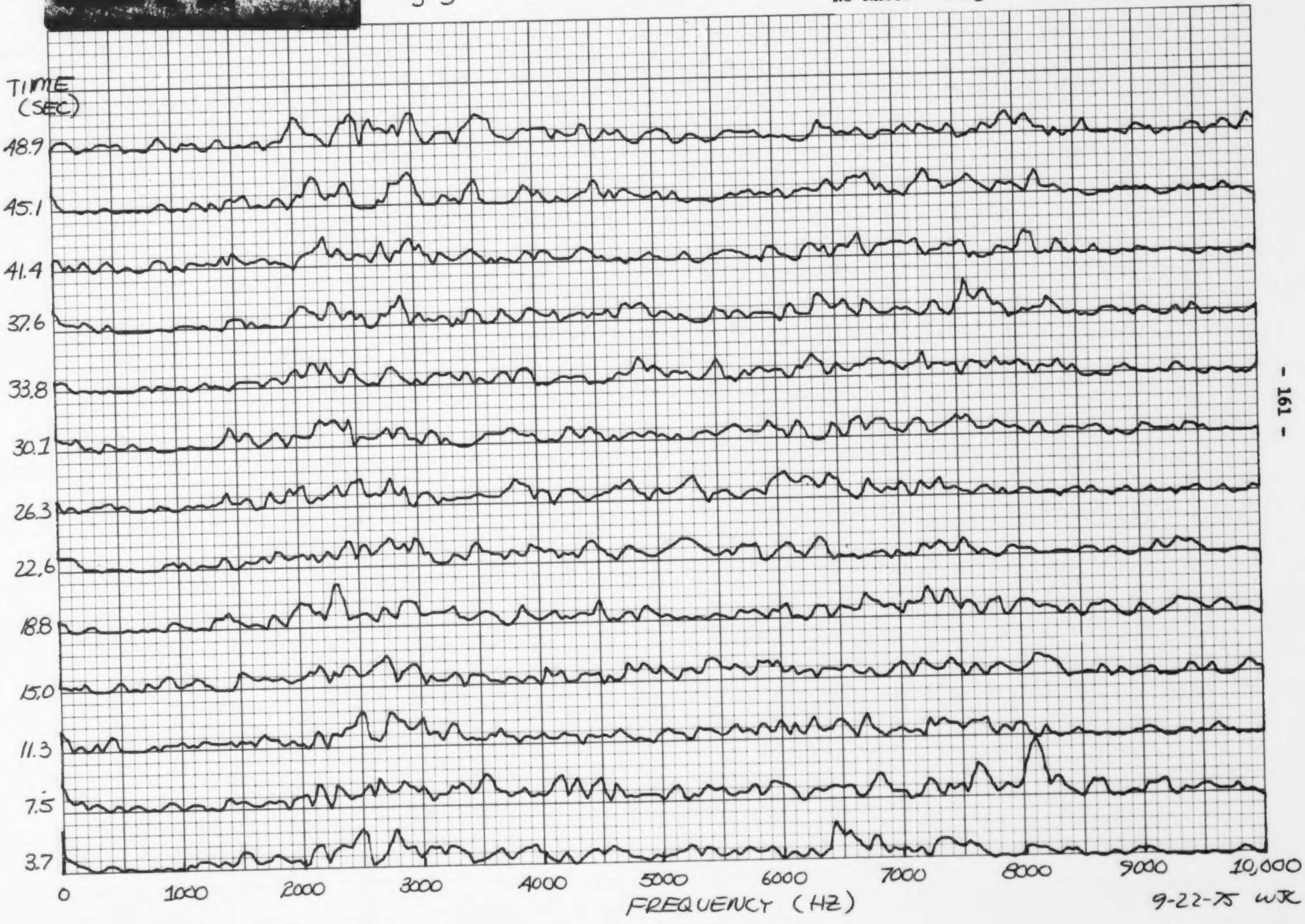
Steady State Test - 78 Octane Fuel
Accelerometer #2 - L.R. Cylinder Head
Vert.
1750 RPM 170 FT LBS Torque 22" HG
No Knock - Slight Surface Ignition



9-22-75 WJC

Steady State Test - 78 Octane Fuel
Accelerometer #3 - R. Intake Manifold
Vert.
1750 RPM 170 FT LBS Torque 22" HG
No Knock - Slight Surface Ignition

#3-3

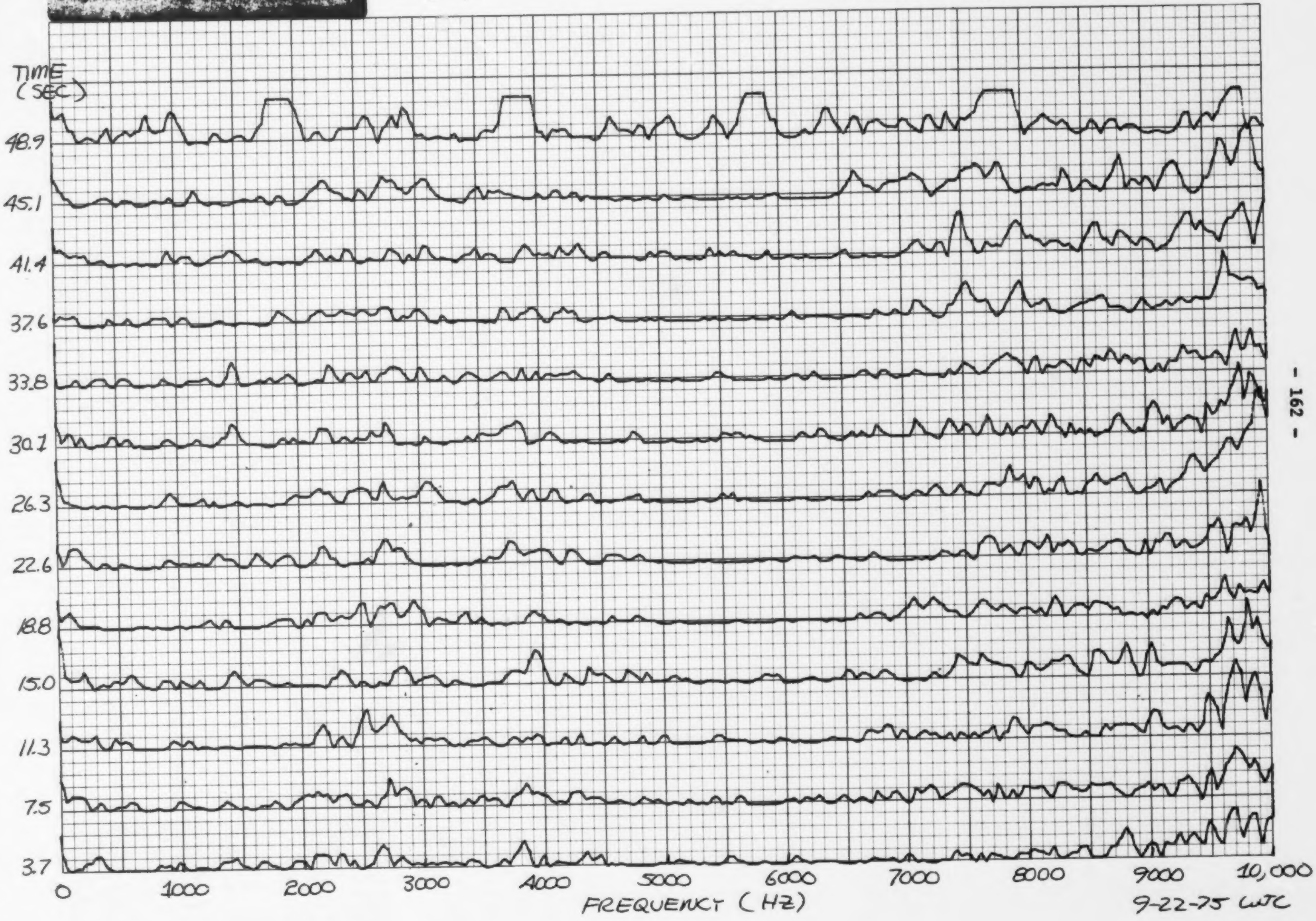


9-22-75 WR

[illegible] Research And Engine[illegible]
[illegible] Co.
[illegible] Detection Test
Test Cell, [illegible] Building 4
September [illegible]

#3-4

Steady State Test - 78 Octane Fuel
Accelerometer #4 - F. Intake Manifold
Vert.
1750 RPM 170 FT LBS Torque 22" HG
No Knock - Slight Surface Ignition

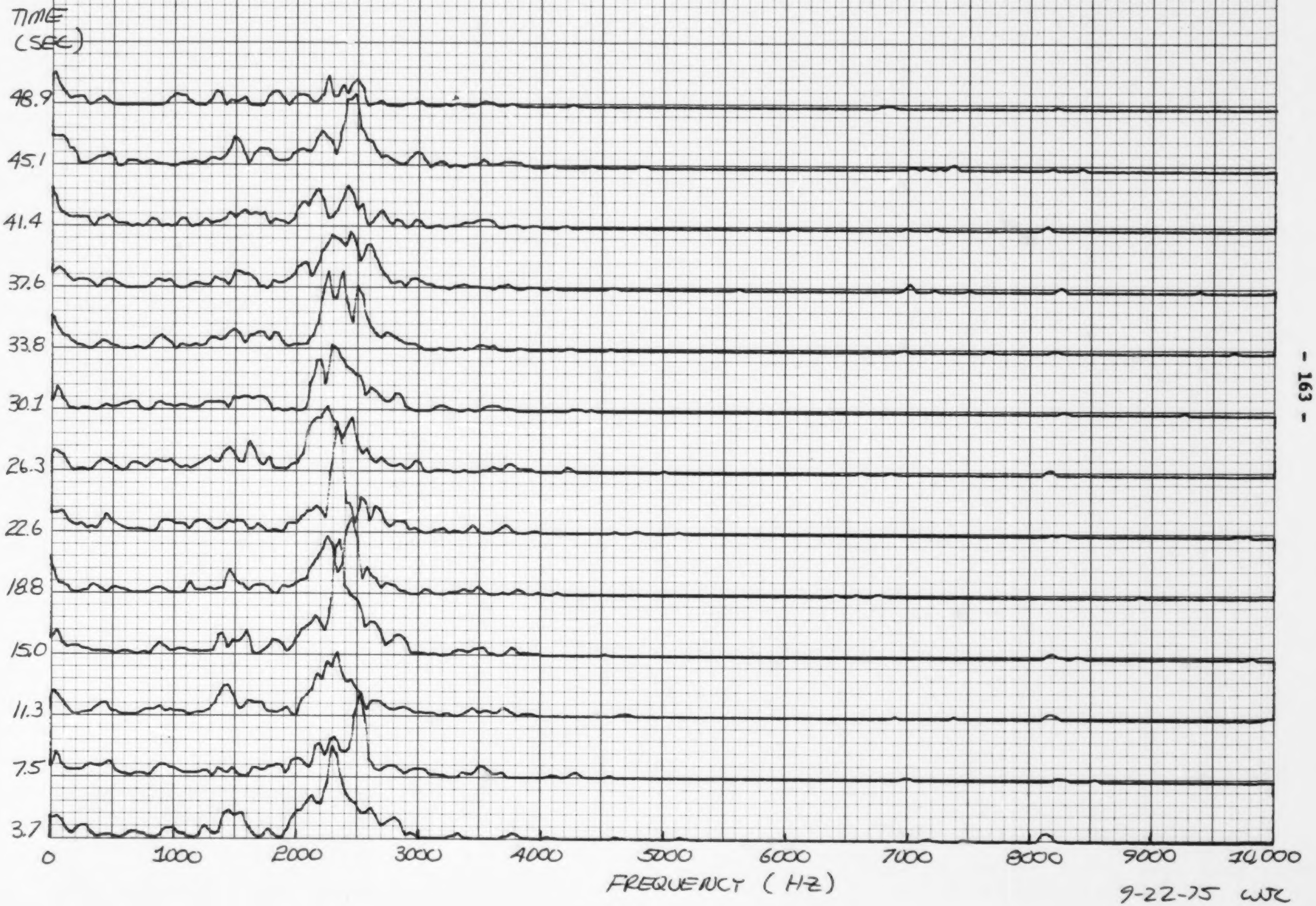


9-22-75 WJC

[illegible] Research and Engi-
neering Co.
[illegible] Detection Test
[illegible] Cell, [illegible] Building 4
[illegible]

#3-5

Steady State Test - 78 Octane Fuel
Accelerometer #5 - R.F. Cylinder Head
Vert.
1750 RPM 170 FT LBS Torque 22" HG
No Knock - Slight Surface Ignition

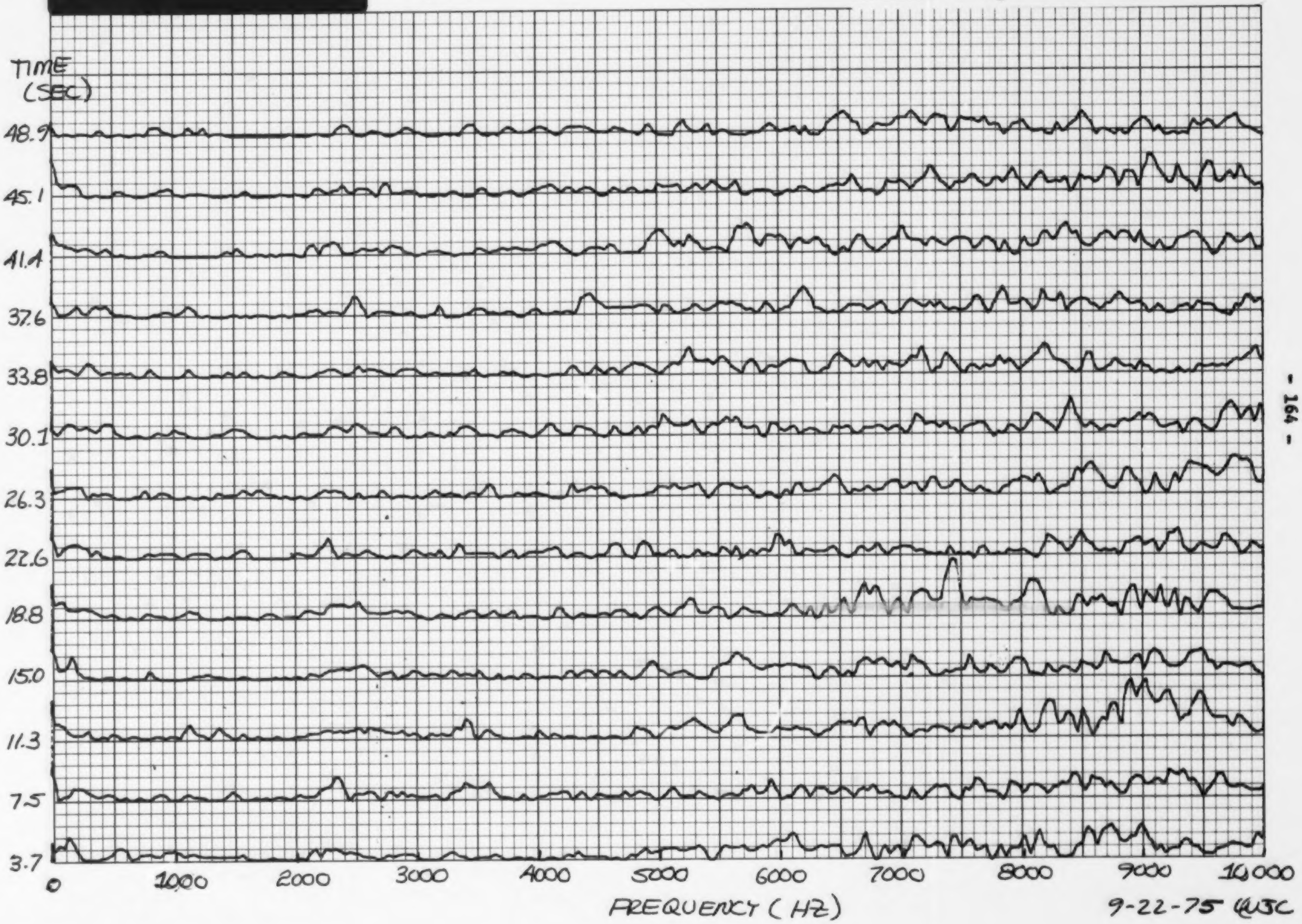


9-22-75 WJC

[redacted]

#3-6

Steady State Test - 78 Octane Fuel
Accelerometer #6 - R.R. Cylinder Head
Hor.
1750 RPM 170 FT LBS Torque 22" HG
No Knock - Slight Surface Ignition

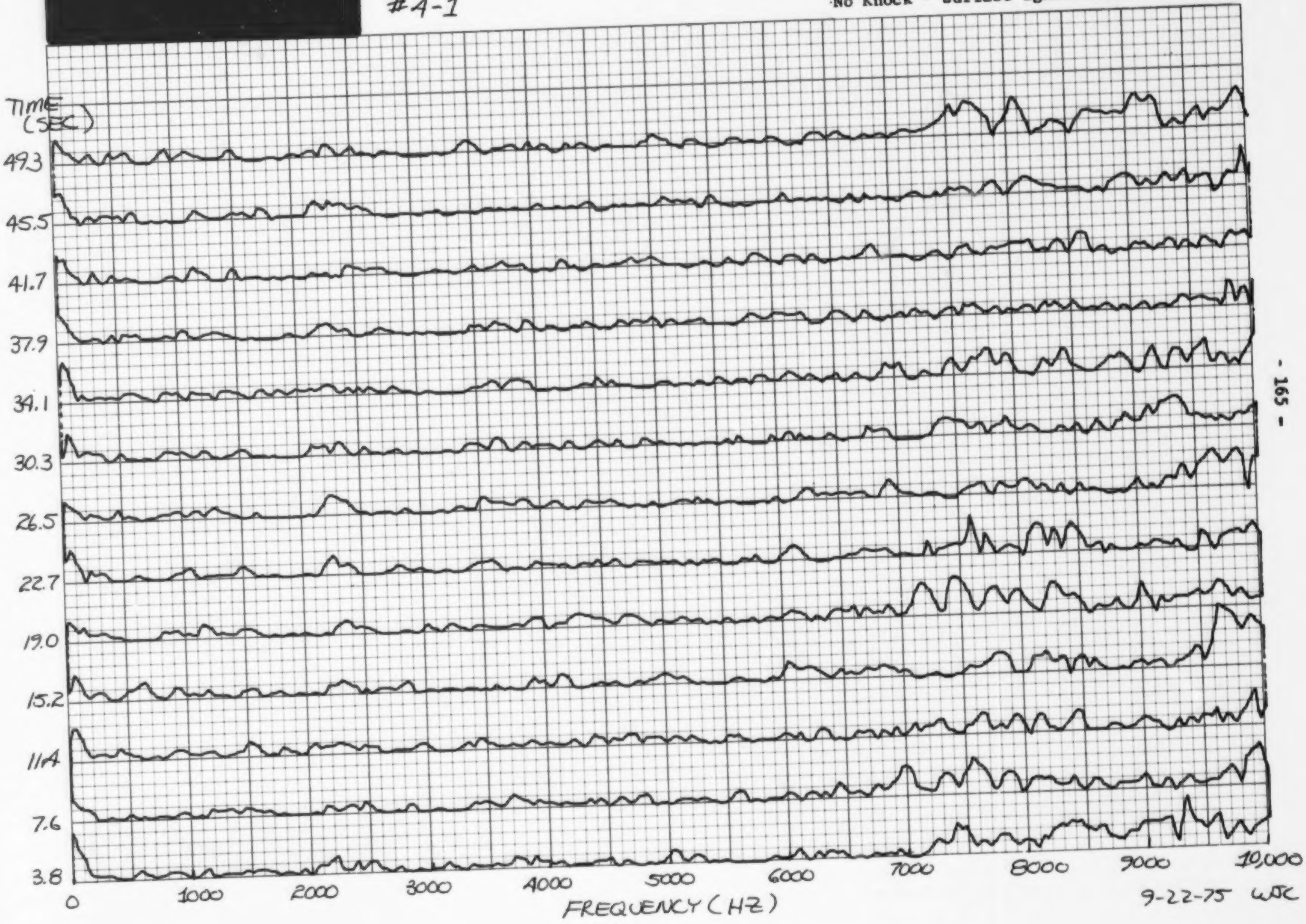


9-22-75 GJC

[redacted]

#4-1

Steady State Test - 78 Octane Fuel
Accelerometer #1 - L.F. Cylinder Head
Vert.
1750 RPM 179 FT LBS 22.5" HG
No Knock - Surface Ignition Present

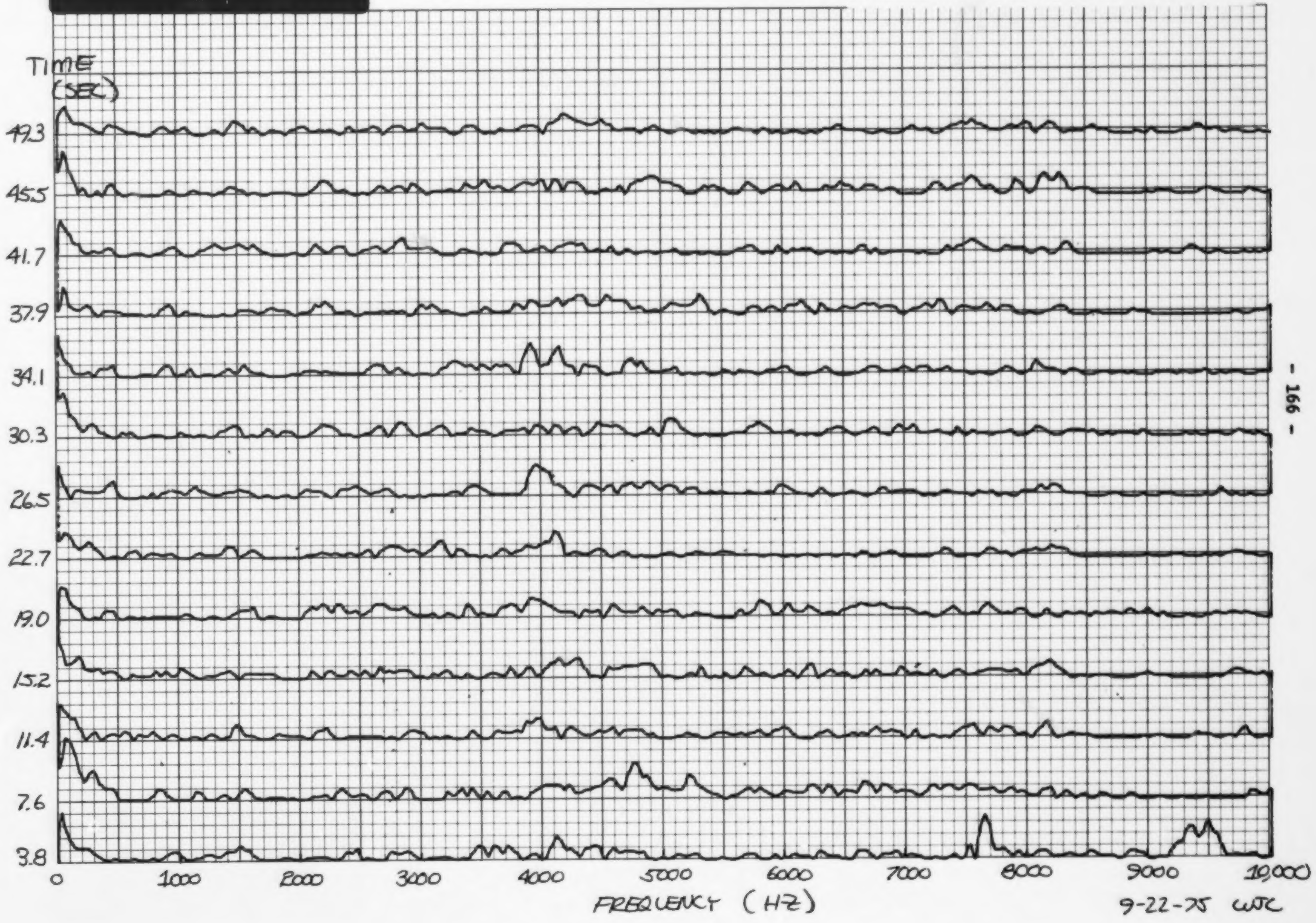


9-22-75 WJC

[redacted]

#4-2

Steady State Test - 78 Octane Fuel
Accelerometer #2 - L.R. Cylinder Head
  Vert.
1750 RPM 179 FT LBS 22.5" HG
No Knock - Surface Ignition Present

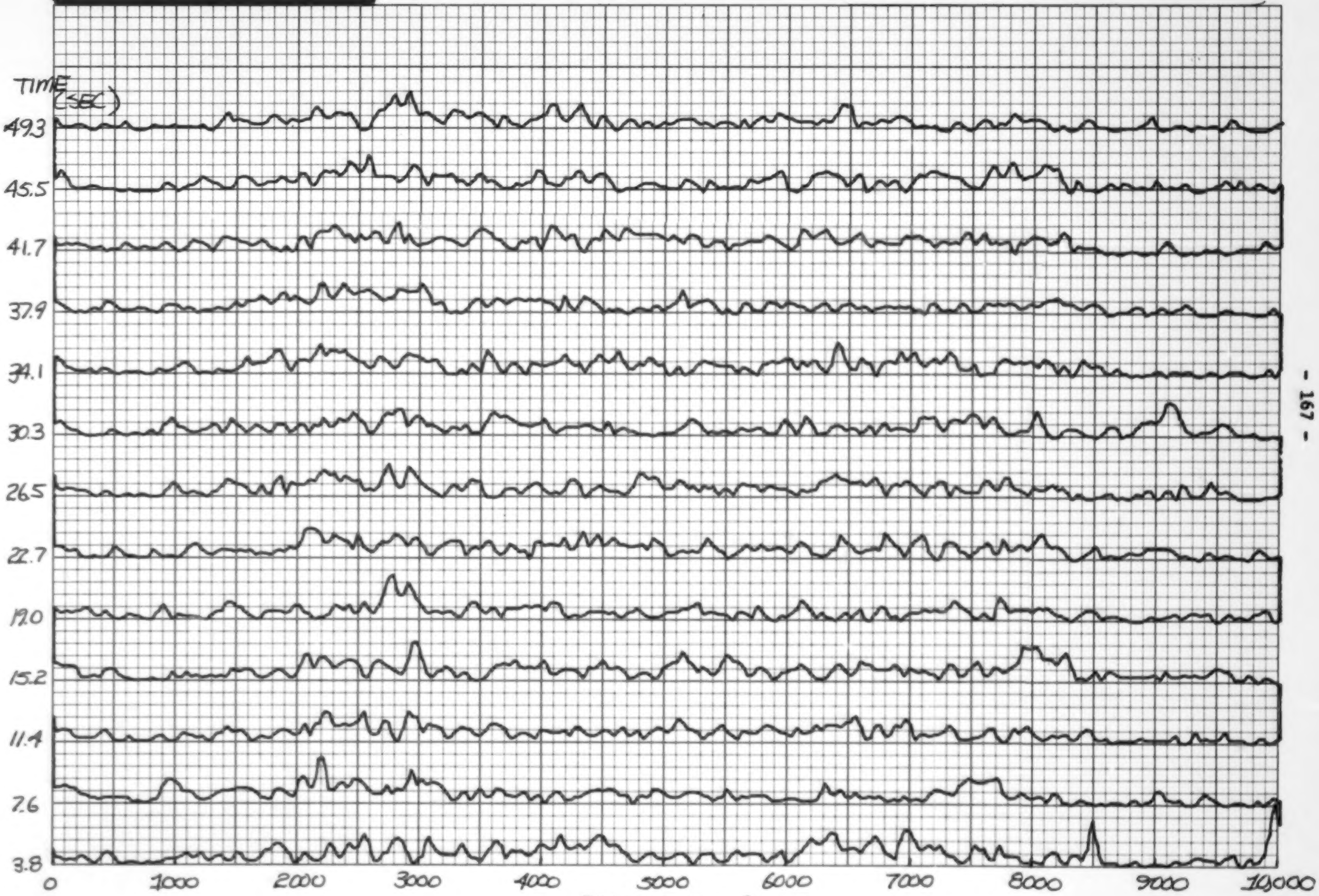


9-22-75 wjc

[redacted]

#4-3

Steady State Test - 78 Octane Fuel
Accelerometer #3 - R. Intake Manifold
Vert.
1750 RPM 179 FT LBS 22.5" HG
No Knock - Surface Ignition Present

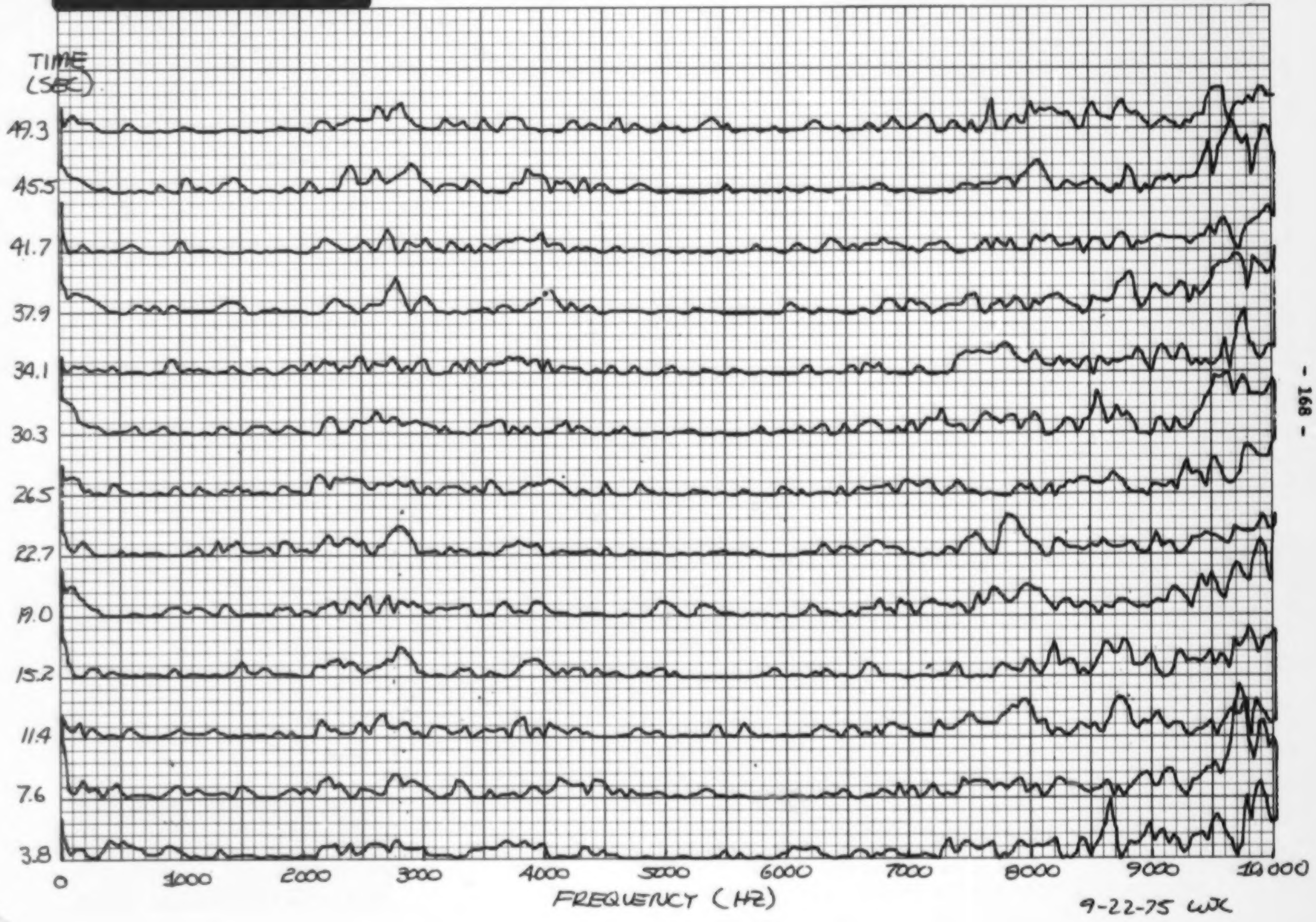


9-22-75 WJC

[redacted]

#4-4

Steady State Test - 78 Octane Fuel
Accelerometer #4 - F. Intake Manifold
Vert.
1750 RPM 179 FT LBS 22.5" HG
No Knock - Surface Ignition Present

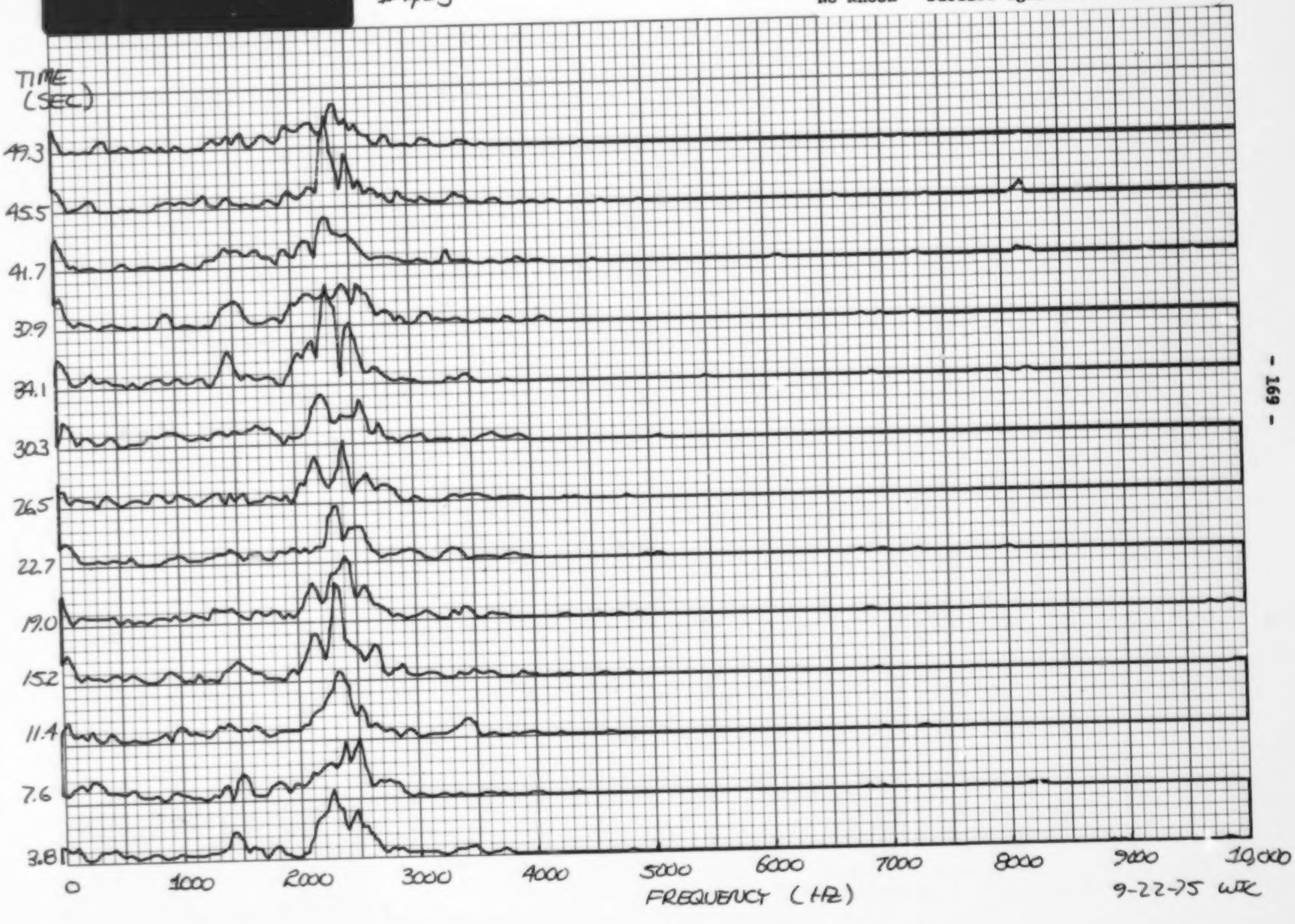


9-22-75 WJK

[redacted]

#4-5

Steady State Test - 78 Octane Fuel
Accelerometer #5 - R.F. Clinder Head
Vert.
1750 RPM 179 FT LBS 22.5" HG
No Knock - Surface Ignition Present

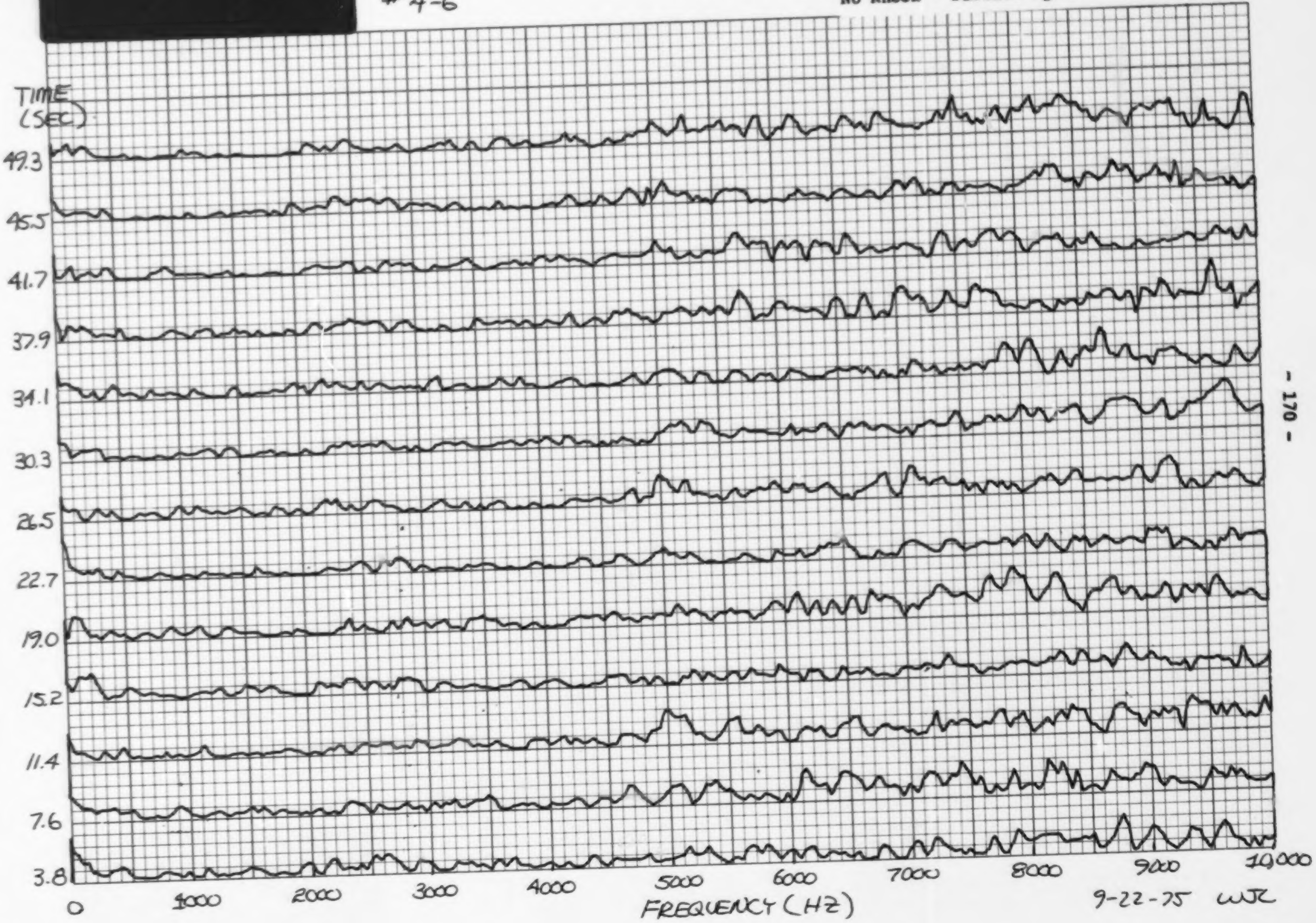


9-22-75 WJC

[redacted]

Steady State Test - 78 Octane Fuel
Accelerometer #6 - R.R. Cylinder Head
Hor.
1750 RPM 179 FT LBS 22.5" HG
No Knock - Surface Ignition Present

#4-6

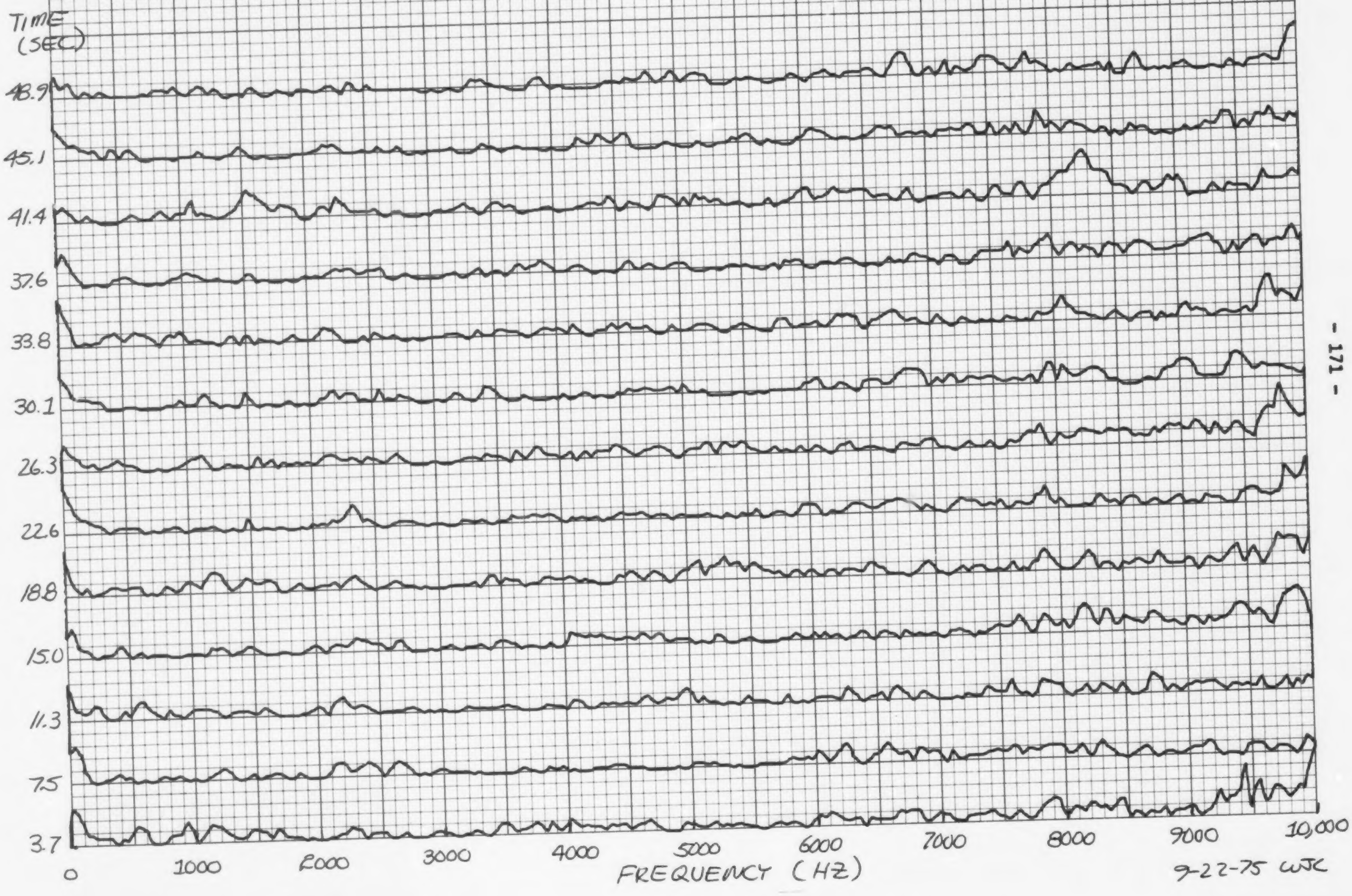


9-22-75 WJC

Steady State Test - 78 Octane Fuel
Accelerometer #1 - L.F. Cylinder Head
Vert.
1750 RPM 200+ FT LBS Torque 24.5" HG
Very Light Plus Level Knock

[redacted]

#5-1

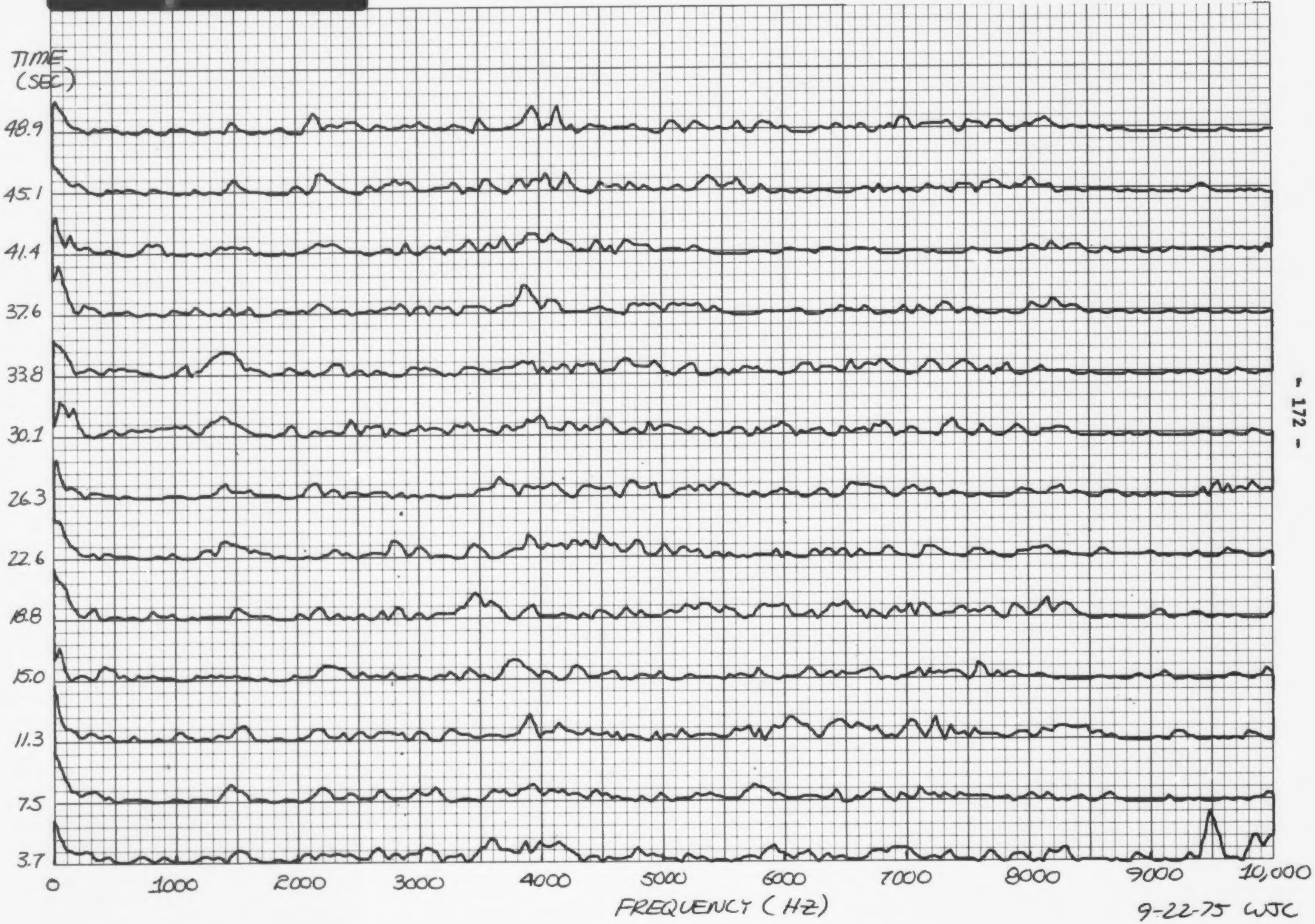


9-22-75 WJC

[redacted]

#5-2

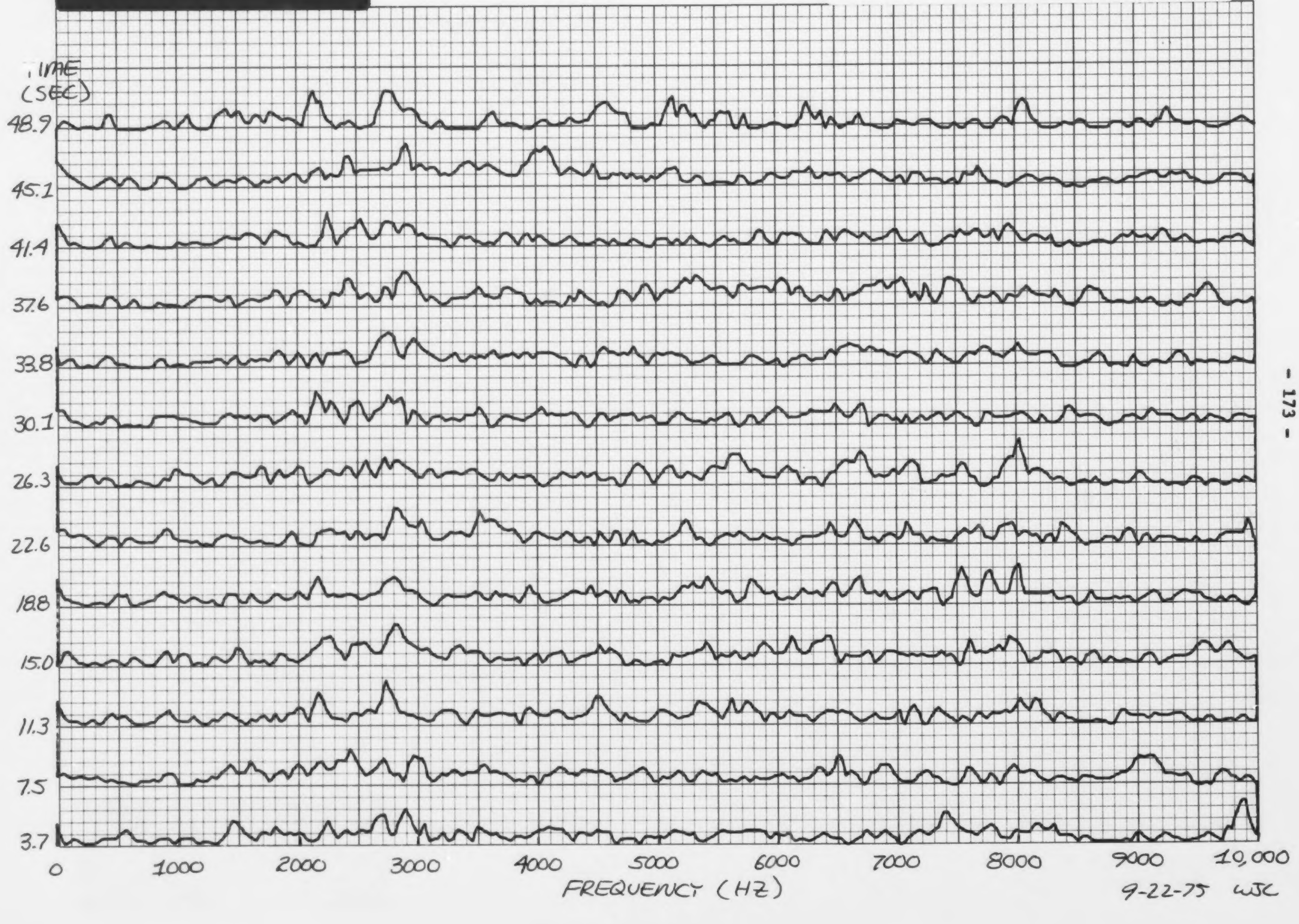
Steady State Test - 78 Octane Fuel
Accelerometer #2 - L.R. Cylinder Head
Vert.
1750 RPM 200+ FT LBS Torque 24.5" HG
Very Light Plus Level Knock



9-22-75 WJC

[redacted]

Steady State Test - 78 Octane Fuel
Accelerometer #3 - R. Intake Manifold
Vert.
1750 RPM 200+ FT LBS Torque 24.5" HG
Very Light Plus Level Knock

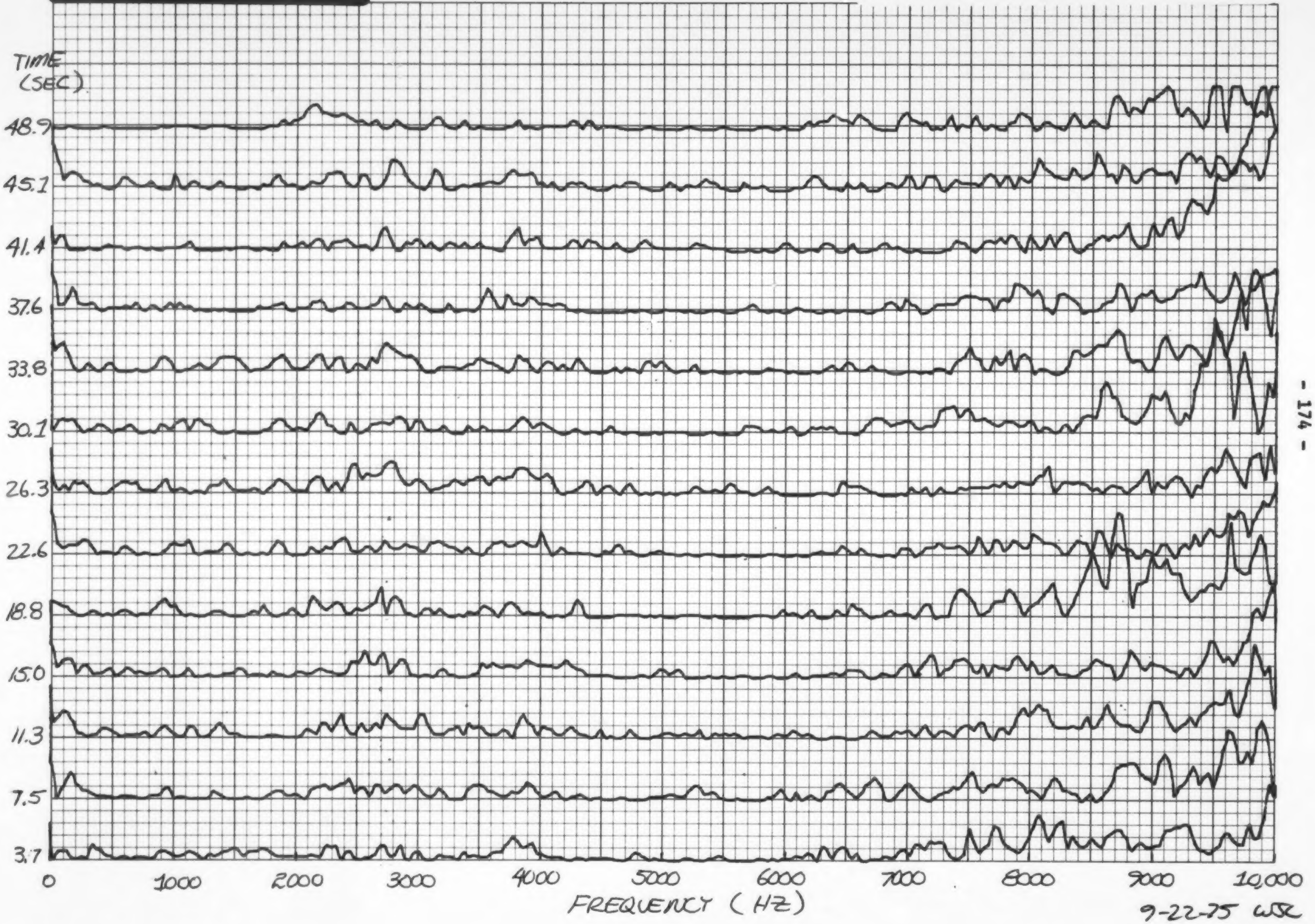


9-22-75 WJC

[redacted]

#5-4

Steady State Test - 78 Octane Fuel
Accelerometer #4 - F. Intake Manifold
Vert.
1750 RPM 200+ FT LBS Torque 24.5" HG
Very Light Plus Level Knock

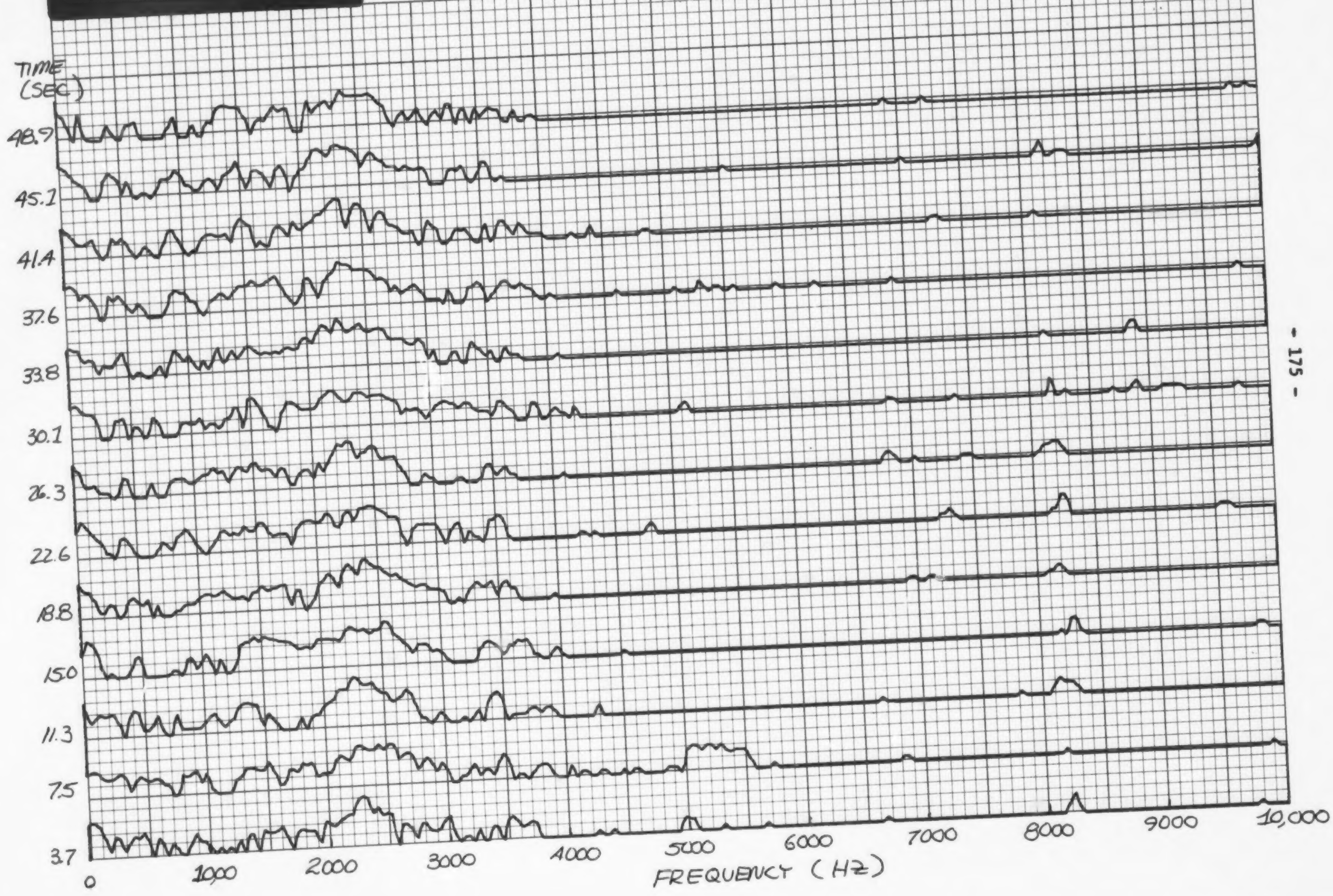


9-22-75 WSC

[redacted]

#5-5

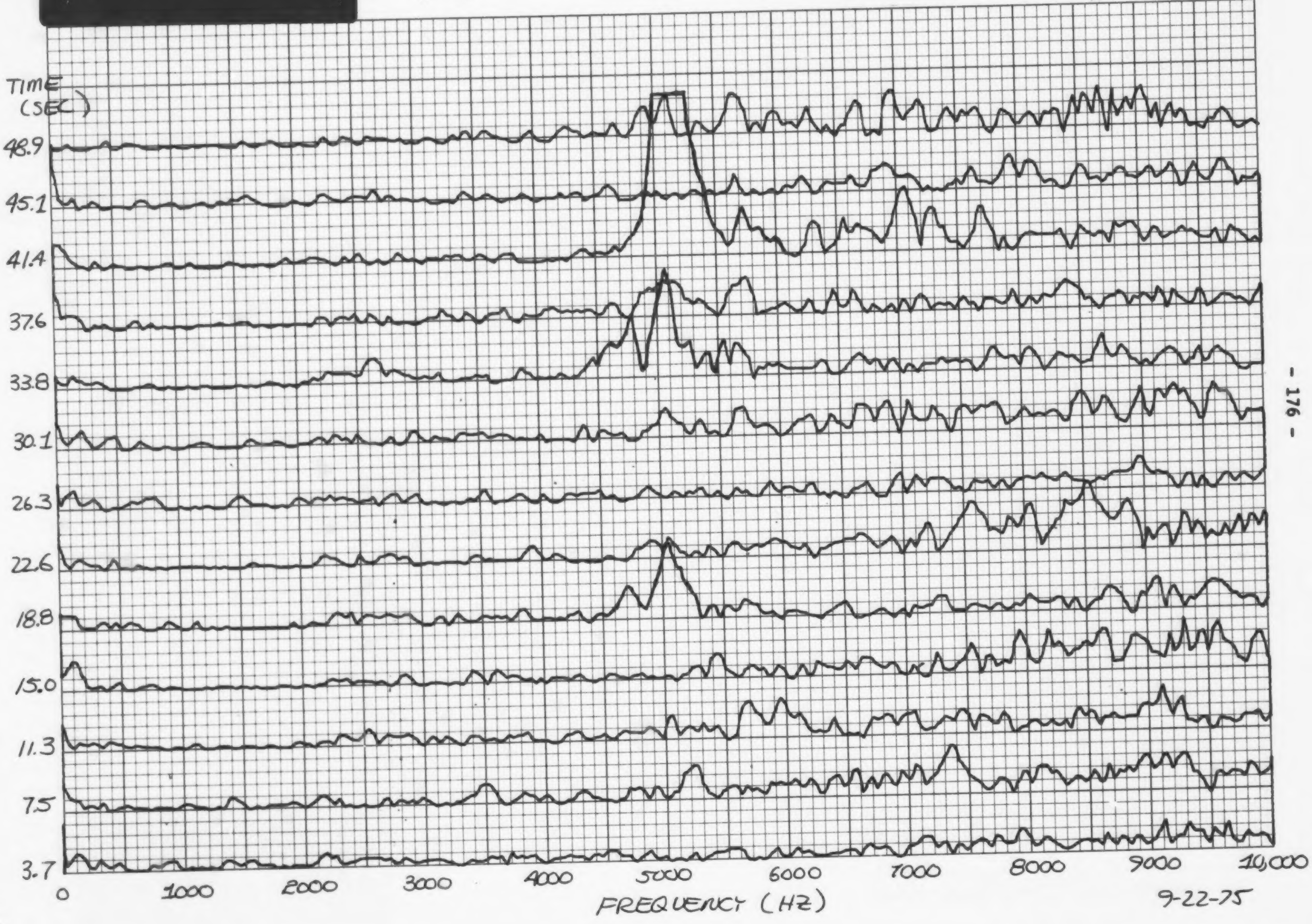
Steady State Test - 78 Octane Fuel
Accelerometer #5 - R.F. Cylinder Head
Vert.
1750 RPM 200+ FT LBS Torque 24.5" HG
Very Light Plus Level Knock



[redacted]

#5-6

Steady State Test - 78 Octane Fuel
Accelerometer #6 - R.R. Cylinder Head
Hor.
1750 RPM 200+ FT LBS Torque 24.5" HG
Very Light Plus Level Knock

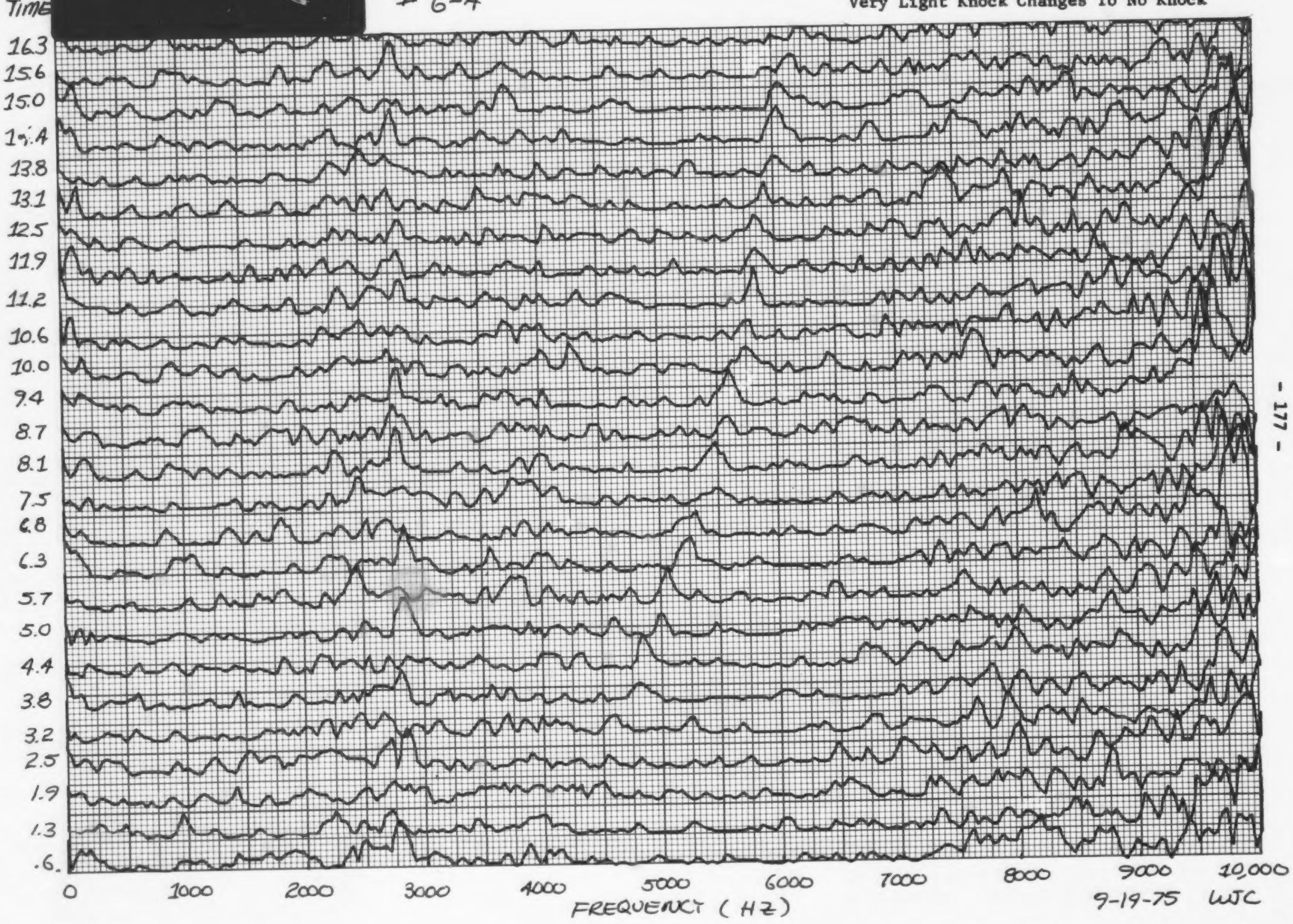


9-22-75

Fuel Change - 78 Octane To House Fuel
Accelerometer #4 - F. Intake Manifold
Vert.
1750 RPM
Very Light Knock Changes To No Knock

[redacted]

6-4

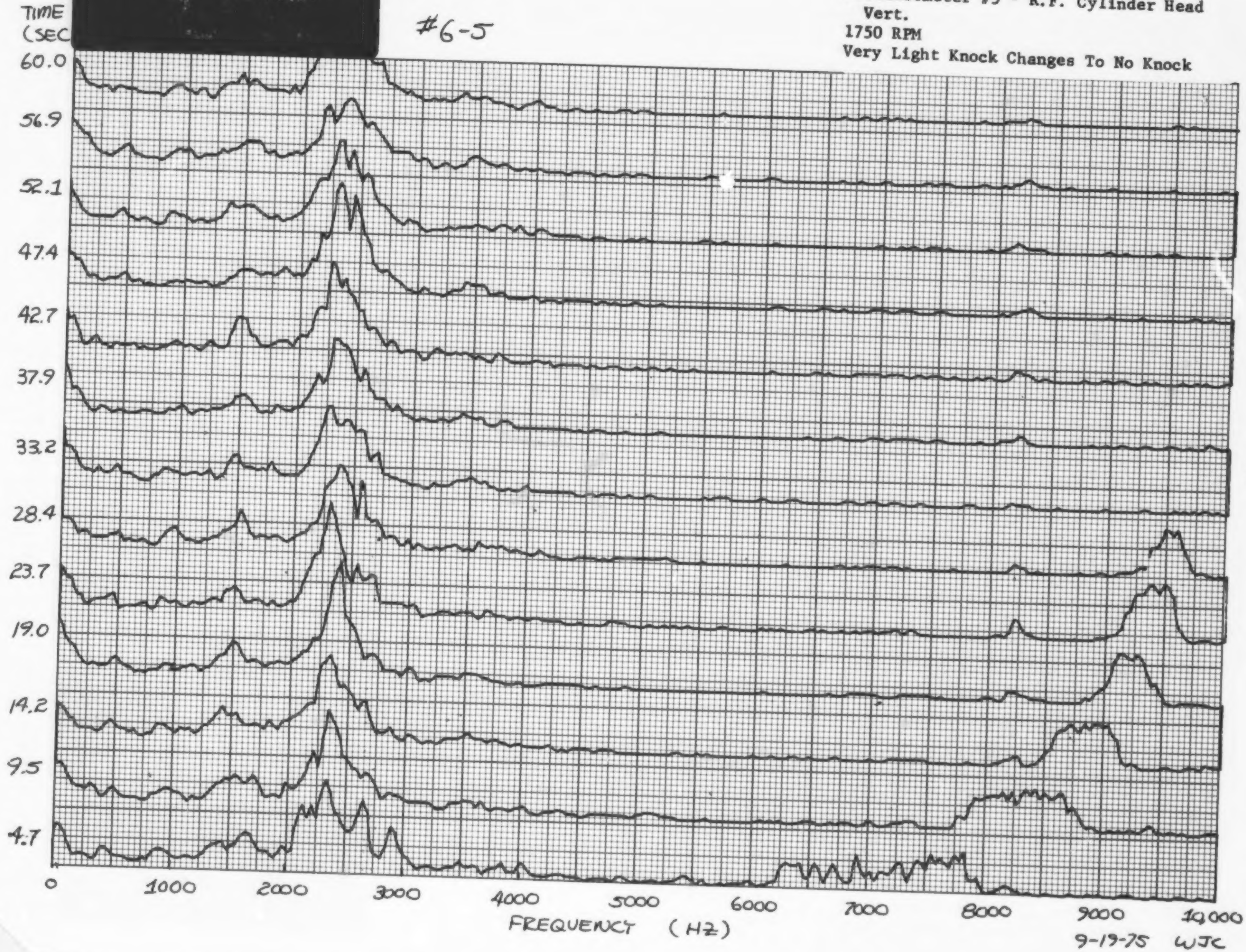


9-19-75 WJC

[redacted]

#6-5

Fuel Change - 78 Octane To House Fuel
Accelerometer #5 - R.F. Cylinder Head
Vert.
1750 RPM
Very Light Knock Changes To No Knock

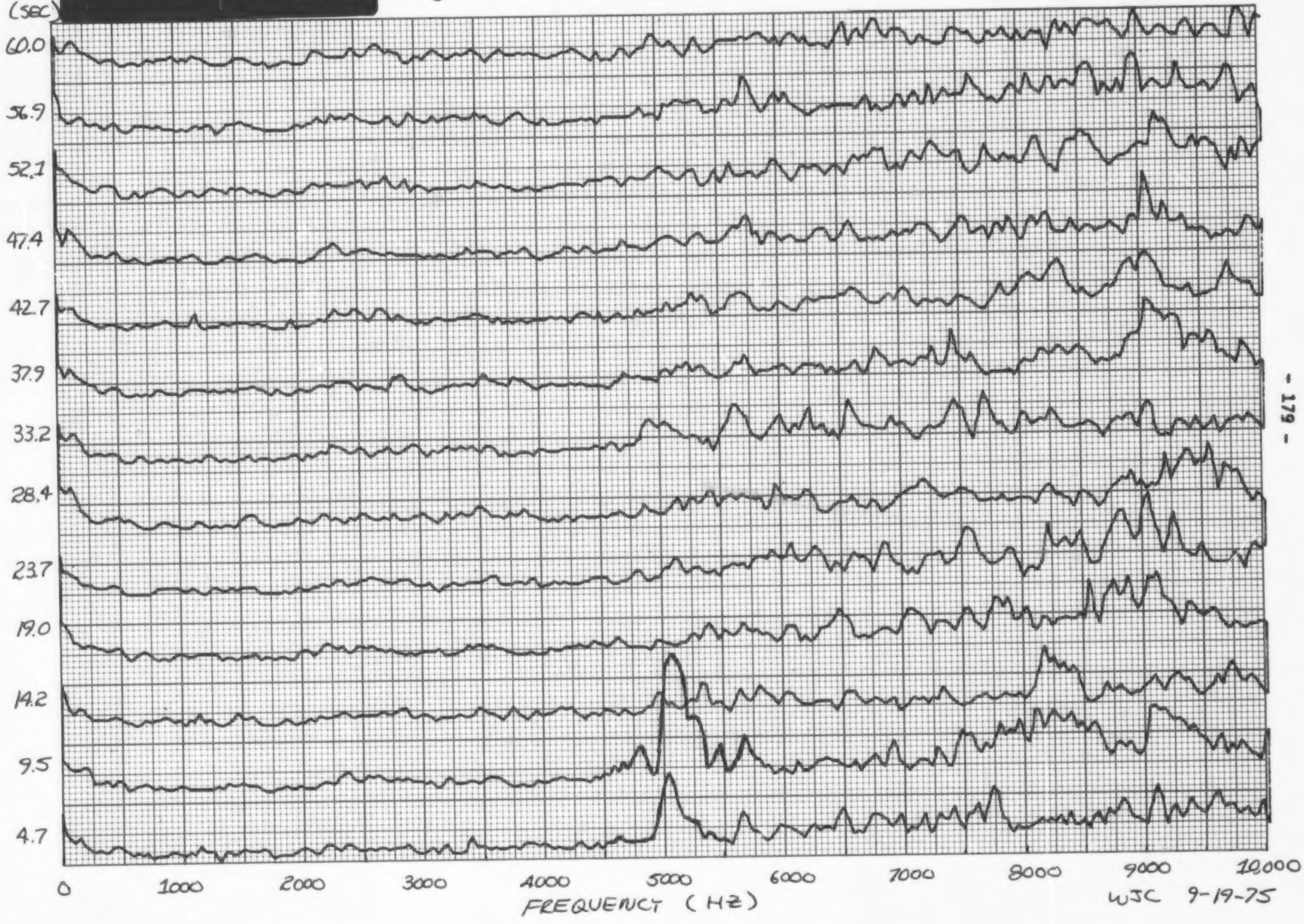


9-19-75 WJC

Fuel Change - 78 Octane To House Fuel
Accelerometer #6 - R.R. Cylinder Head
Hor.
1750 RPM
Very Light Knock Changes To No Knock

[redacted]

#6-6

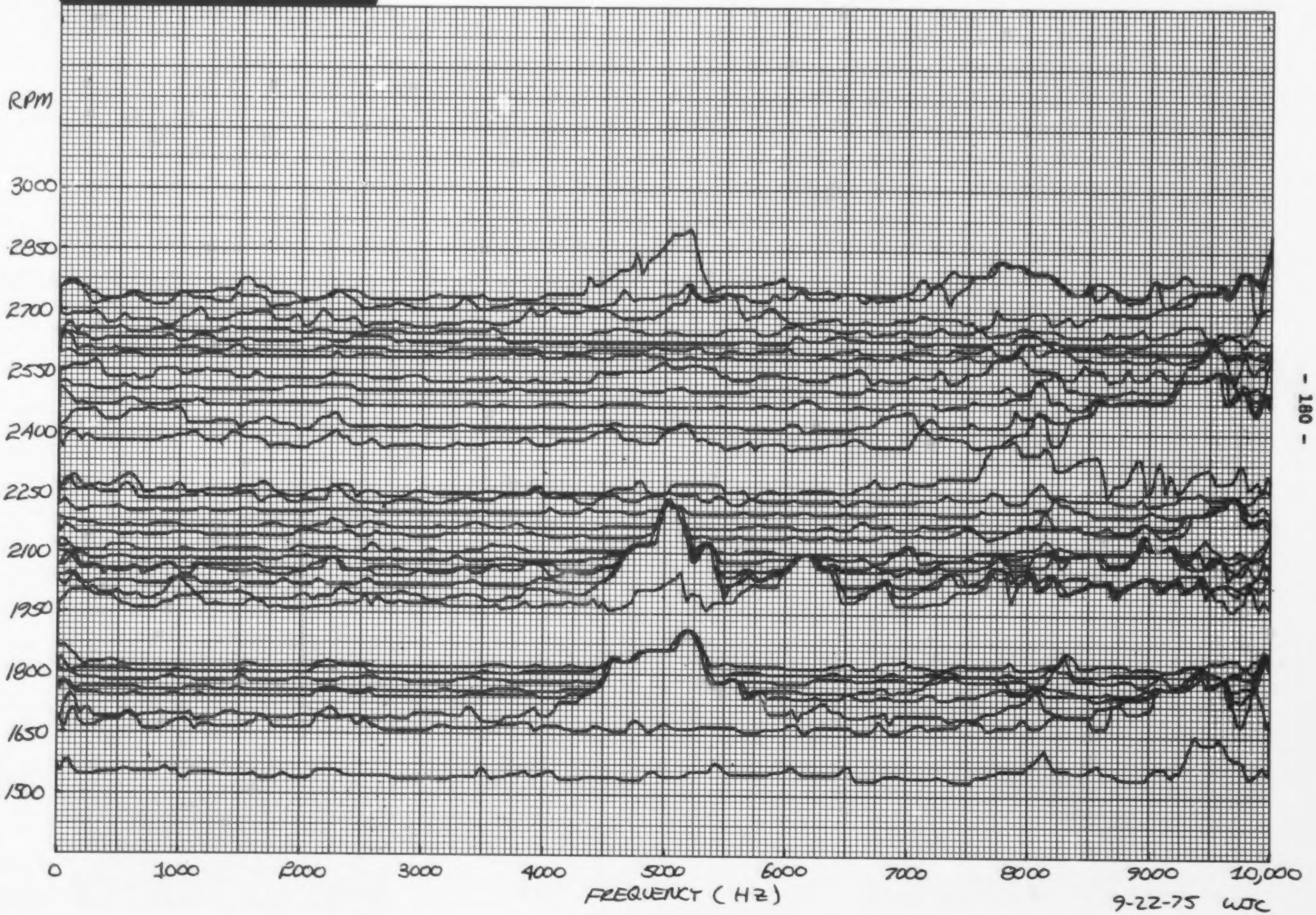


WJC 9-19-75

[redacted]

#7-1

Acceleration Test - 78 Octane Fuel
Accelerometer #1 - L.F. Cylinder Head
  Vert.
1700 70 2900 RPM
No Knock To Light Minus Knock

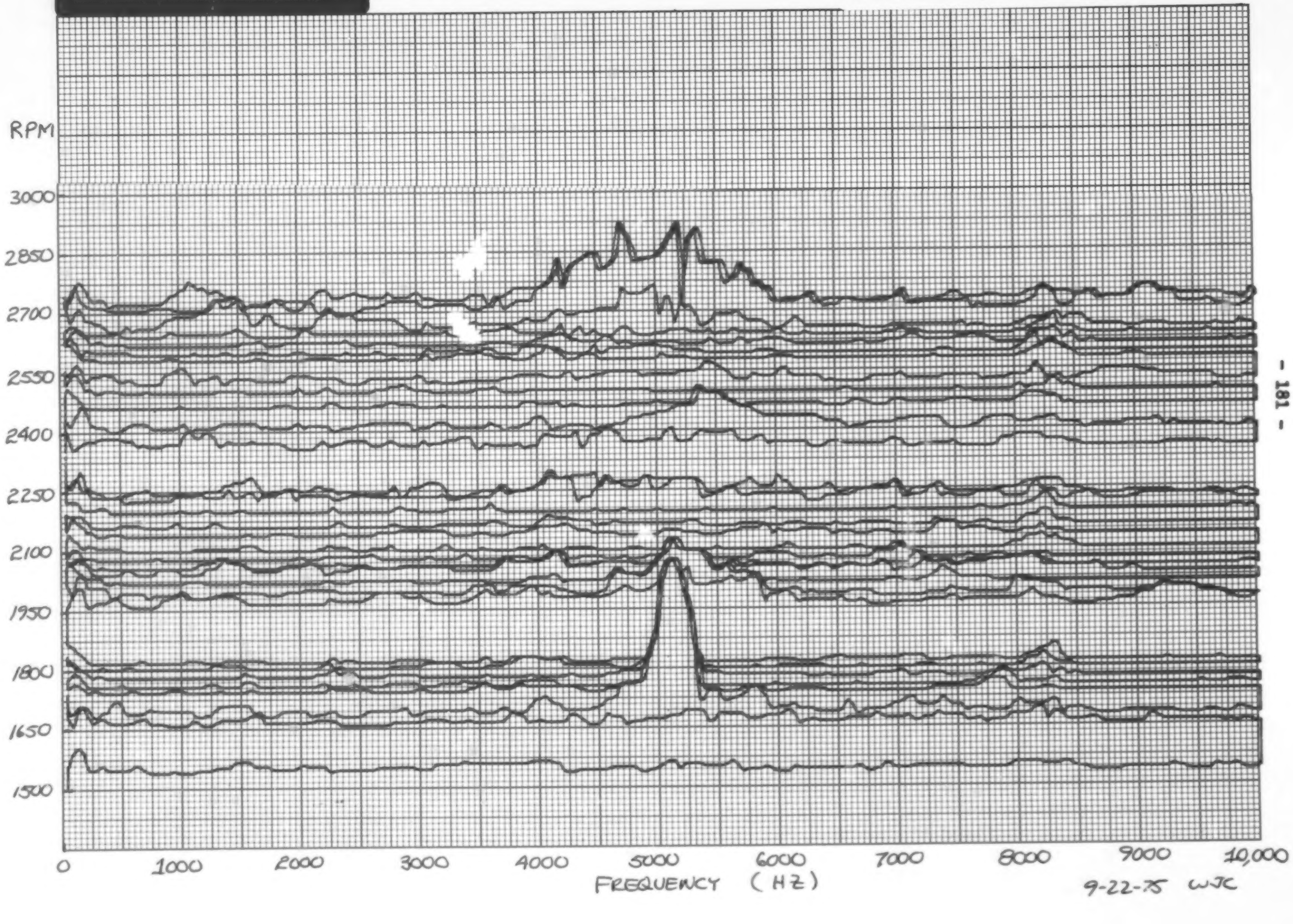


9-22-75 WJC

[redacted]

#7-2

Acceleration Test - 78 Octane Fuel
Accelerometer #2 - L.R. Cylinder Head
Vert.
1700 70 2900 RPM
No Knock To Light Minus Knock

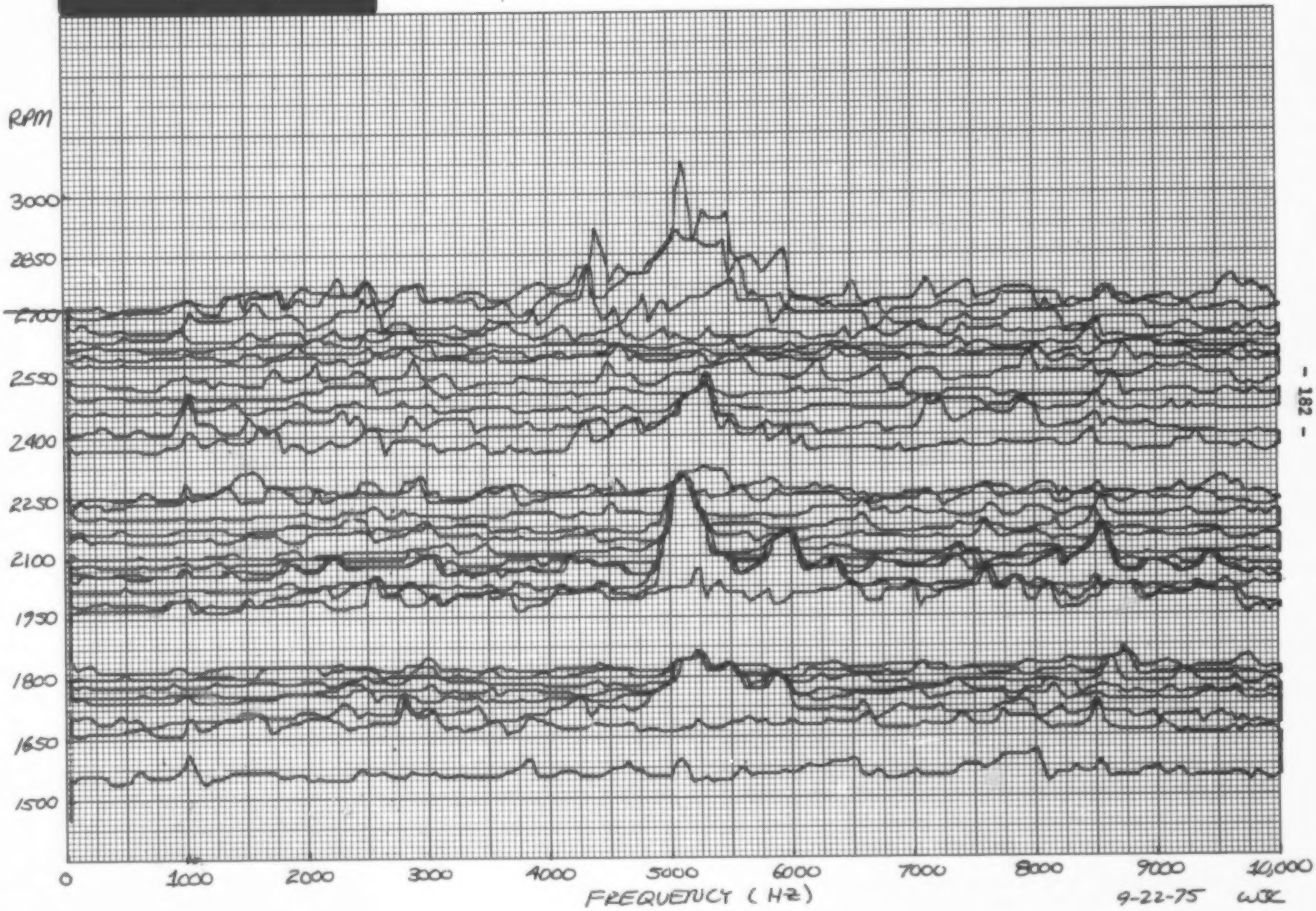


9-22-75 WJC

[redacted]

#7-3

Acceleration Test - 78 Octane Fuel
Accelerometer #3 - R. Intake Manifold
Vert.
1700 70 2900 RPM
No Knock To Light Minus Knock

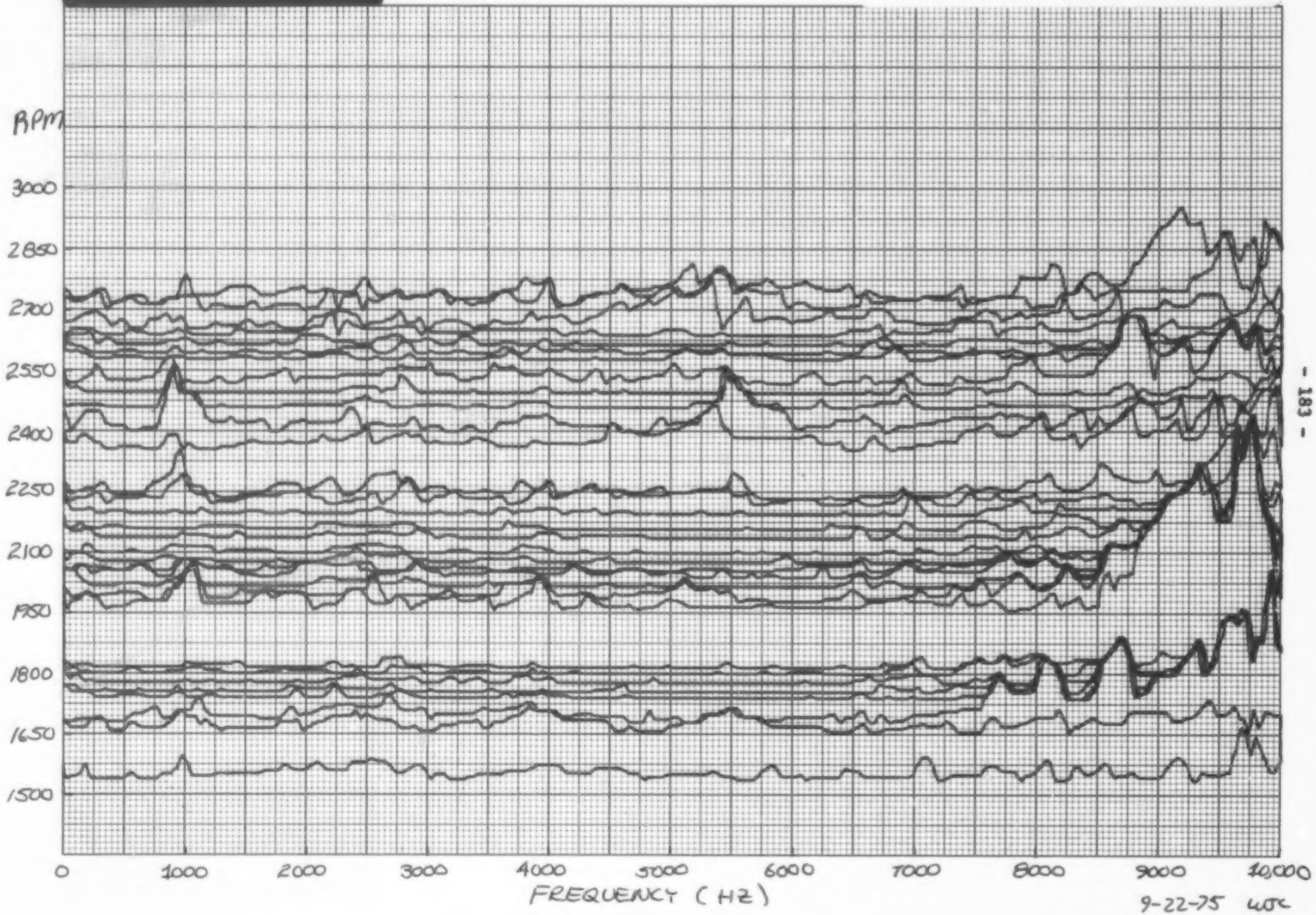


9-22-75 WJC

[redacted]

#7-4

Acceleration Test - 78 Octane Fuel
Accelerometer #4 - F. Intake Manifold
Vert.
1700 70 2900 RPM
No Knock To Light Minus Knock

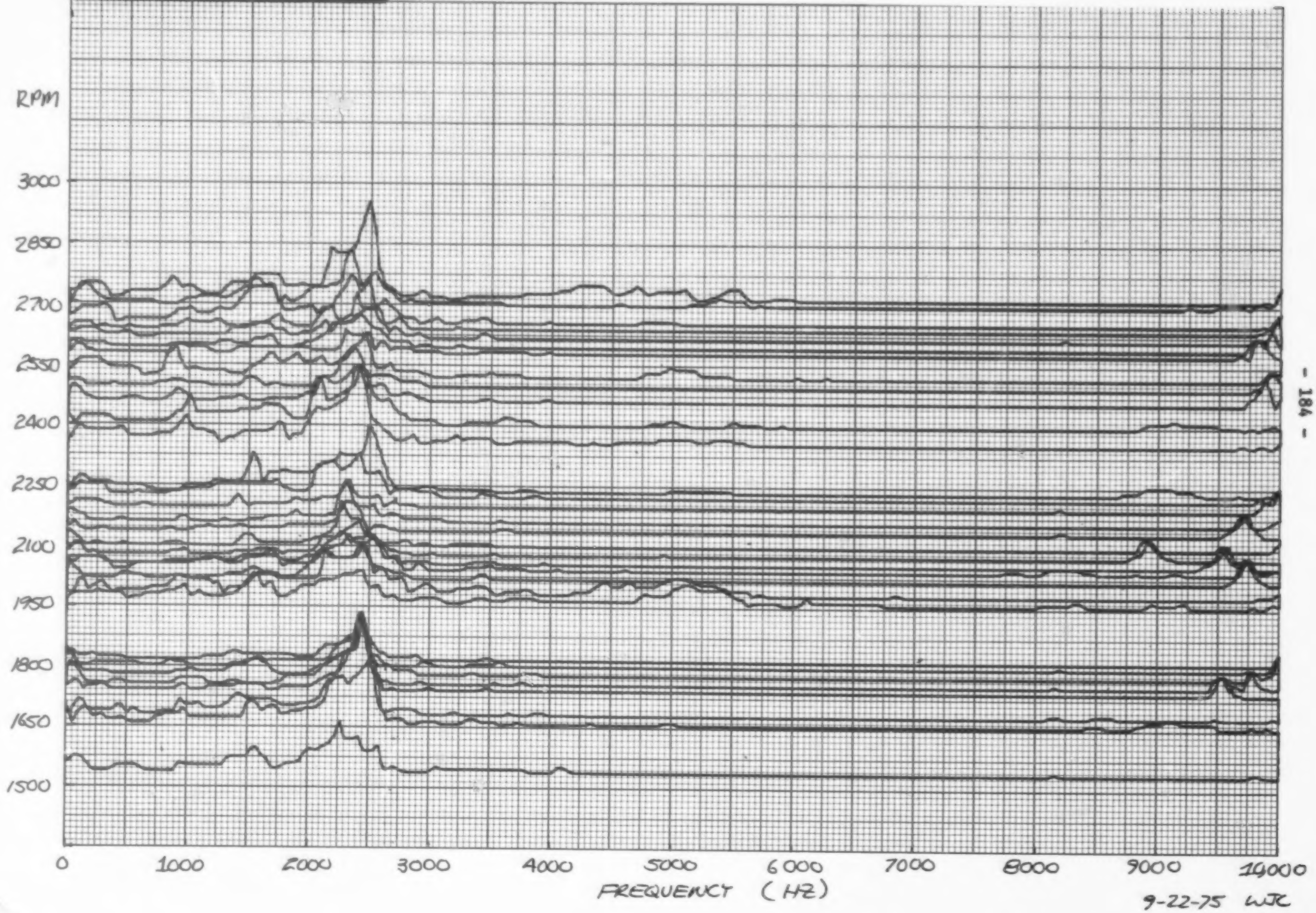


9-22-75 wjc

[redacted]

#7-5

Acceleration Test - 78 Octane Fuel
Accelerometer #5 - R.F. Cylinder Head
  Vert.
1700 70 2900 RPM
No Knock To Light Minus Knock

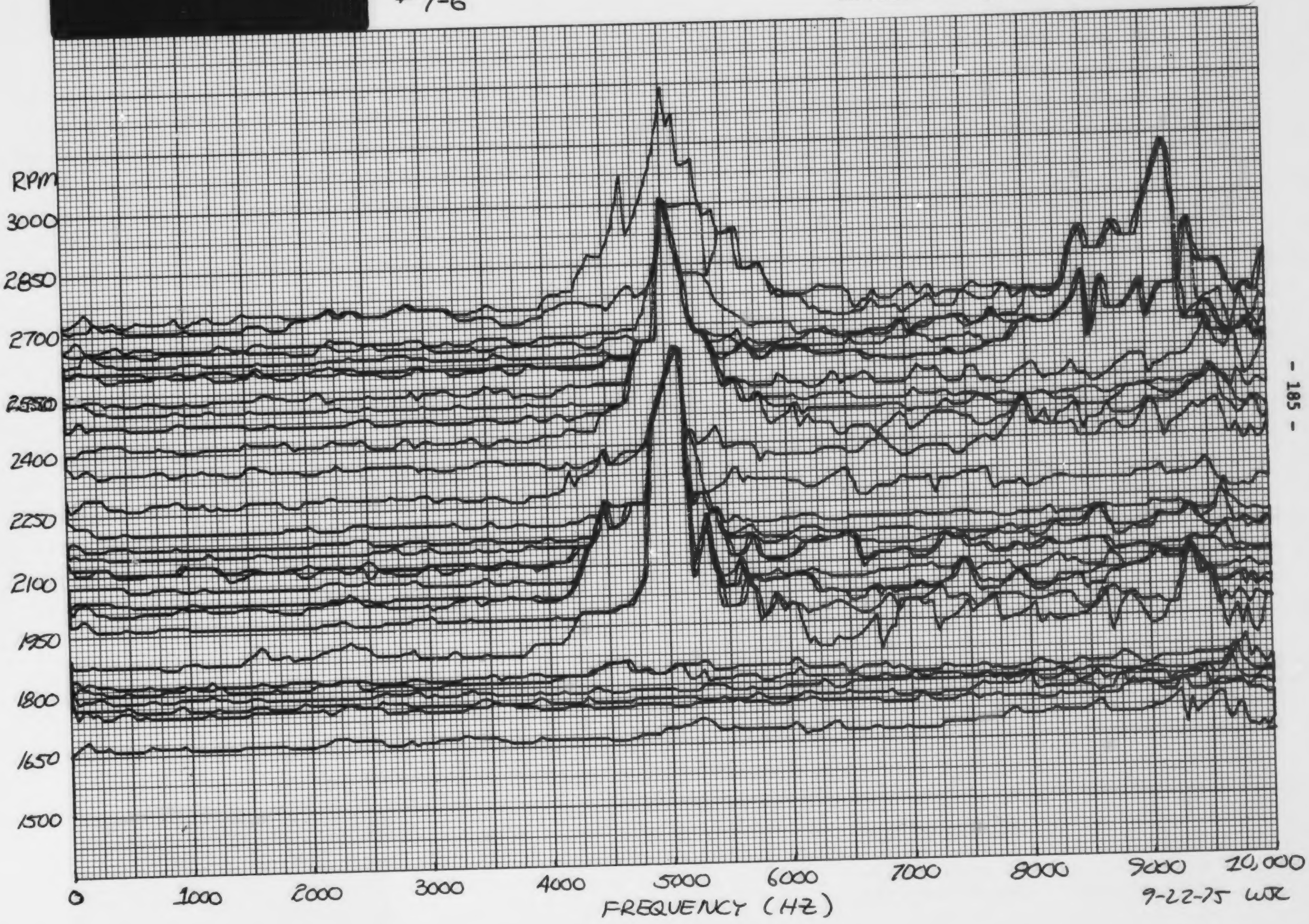


9-22-75 WJC

[redacted]

#7-6

Acceleration Test - 78 Octane Fuel
Accelerometer #6 - R.R. Cylinder Head
Hor.
1700 70 2900 RPM
No Knock To Light Minus Knock

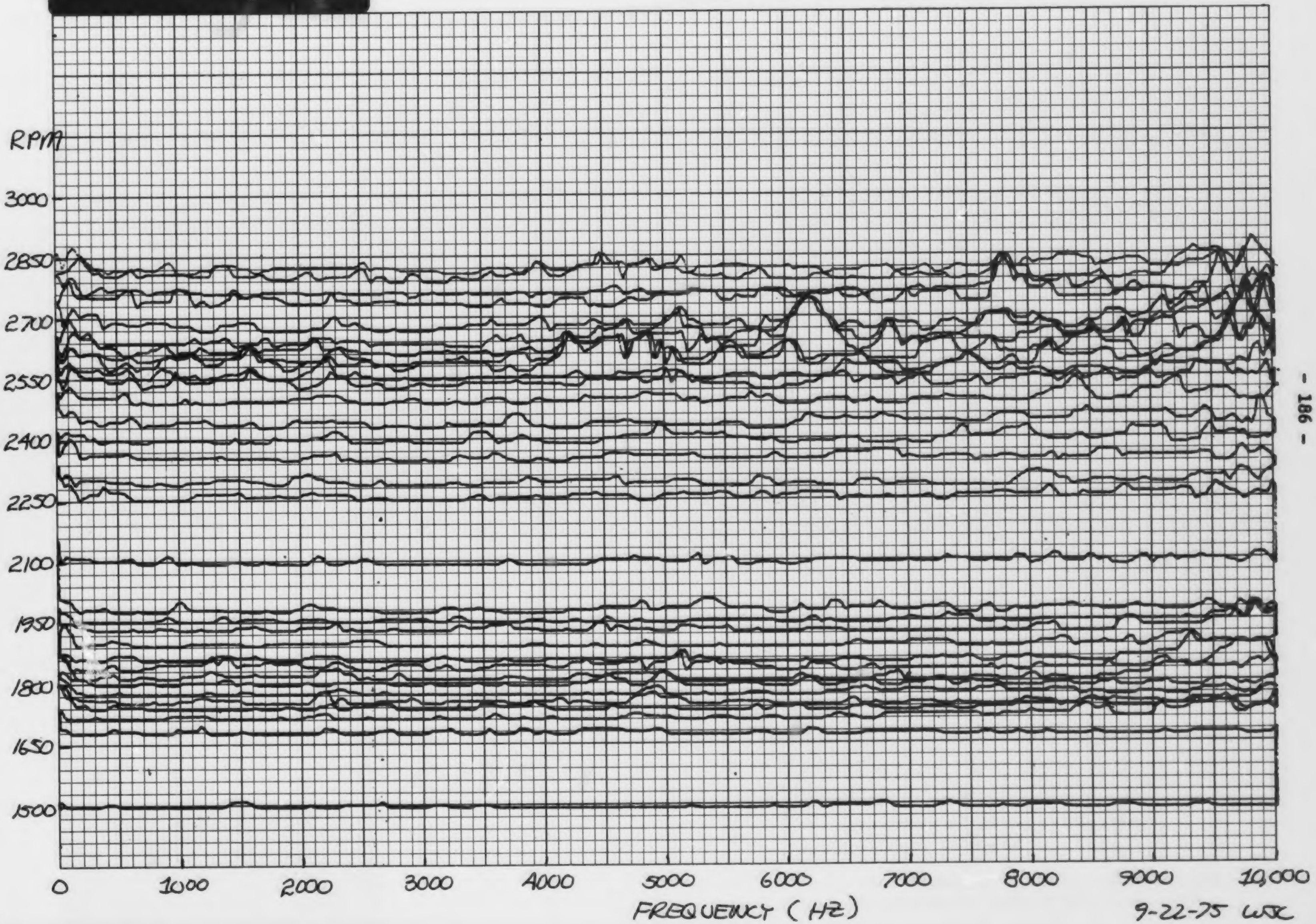


9-22-75 WJC

[redacted]

#8-1

Acceleration Test - 78 Octane Fuel
Accelerometer #1 - L.F. Cylinder Head
Vert.
1700 to 2900 RPM

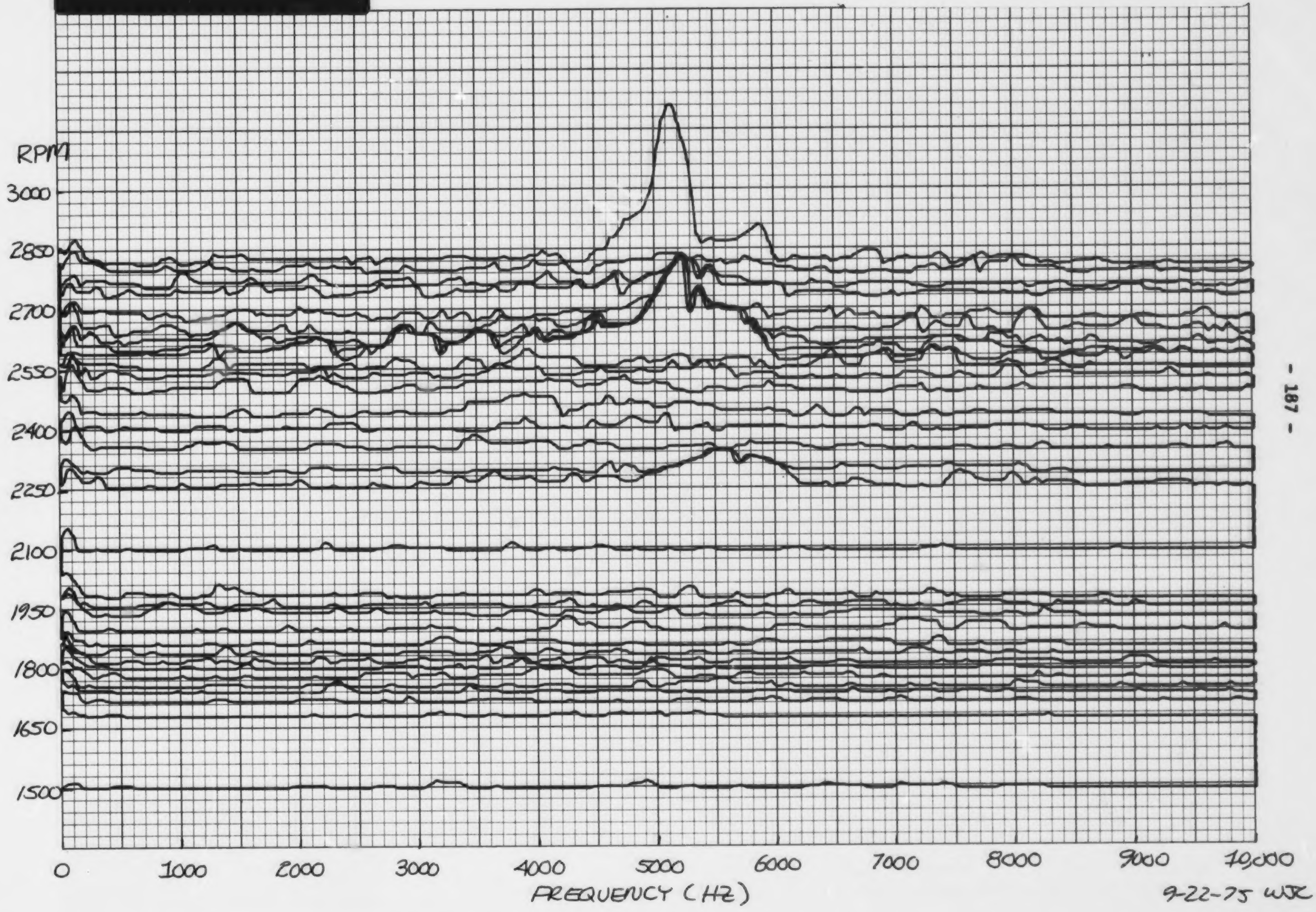


9-22-75 WJC

[redacted]

#8-2

Acceleration Test - 78 Octane Fuel
Accelerometer #2 - L.R. Cylinder Head
  Vert.
1700 to 2900 RPM

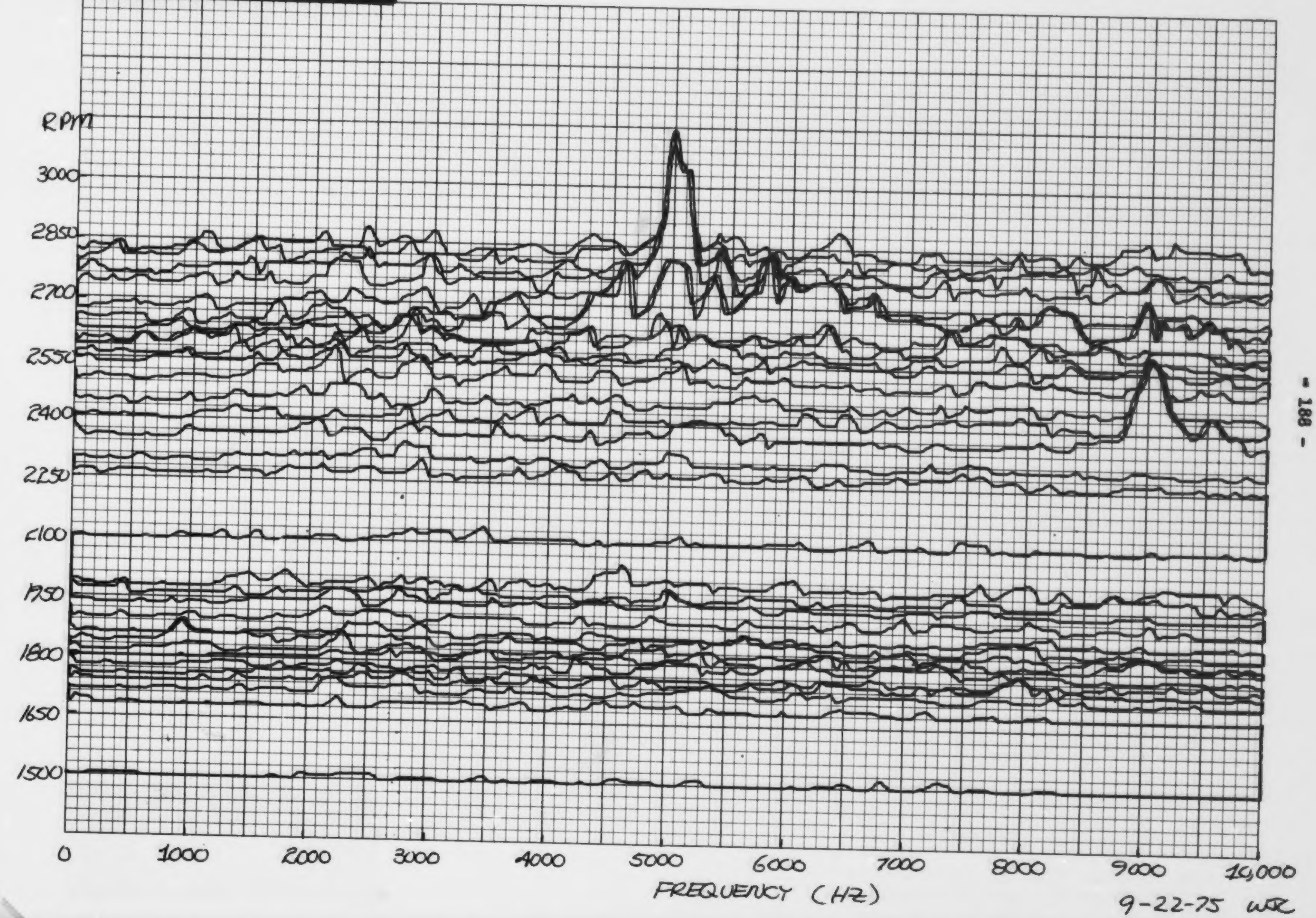


9-22-75 WJC

[redacted]

#8-3

Acceleration Test - 78 Octane Fuel
Accelerometer #3 - R. Intake Manifold
Vert.
1700 to 2900 RPM

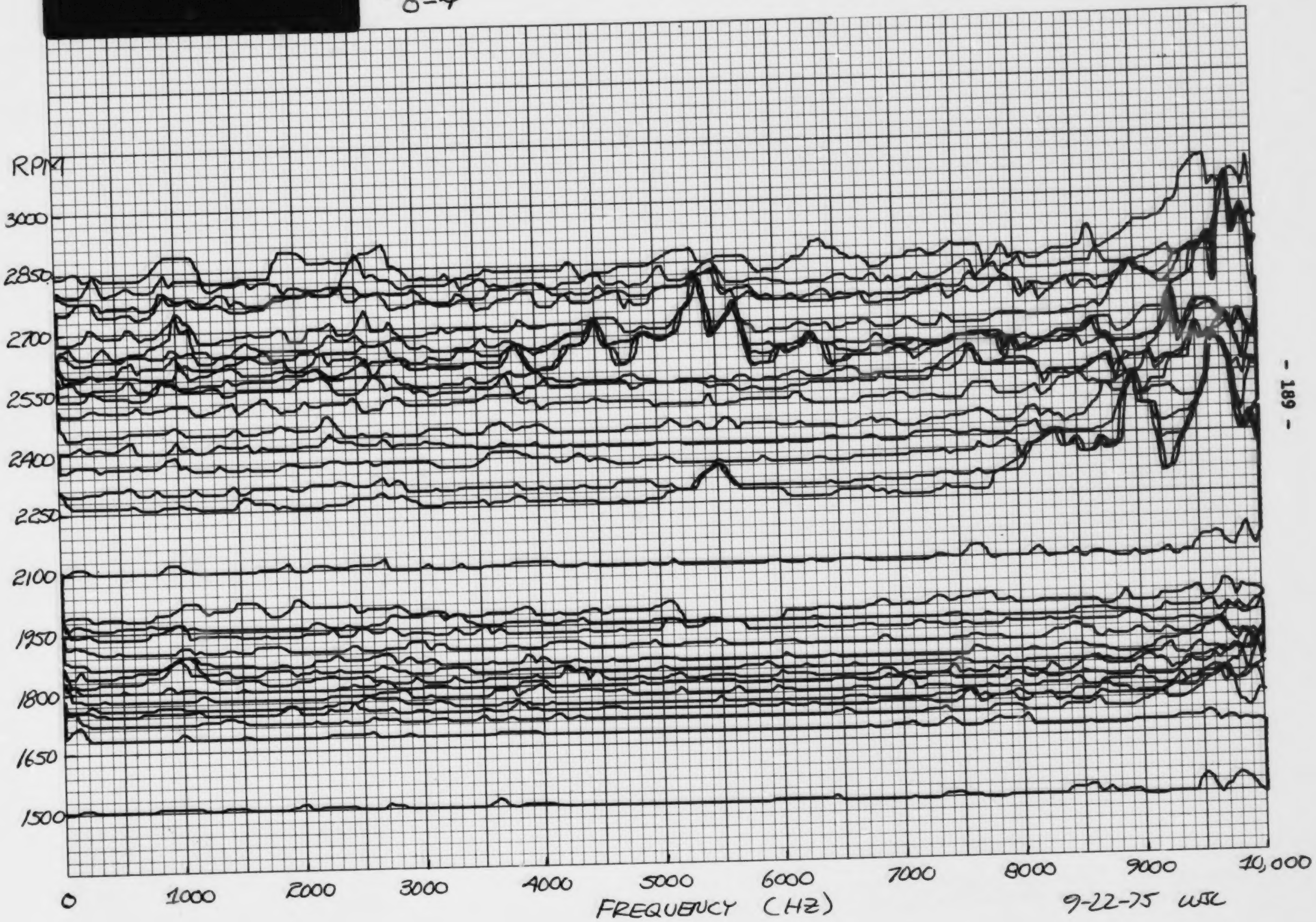


9-22-75 WR

[redacted]

#8-4

Acceleration Test - 78 Octane Fuel
Accelerometer #4 - F. Intake Manifold
  Vert.
1700 to 2900 RPM

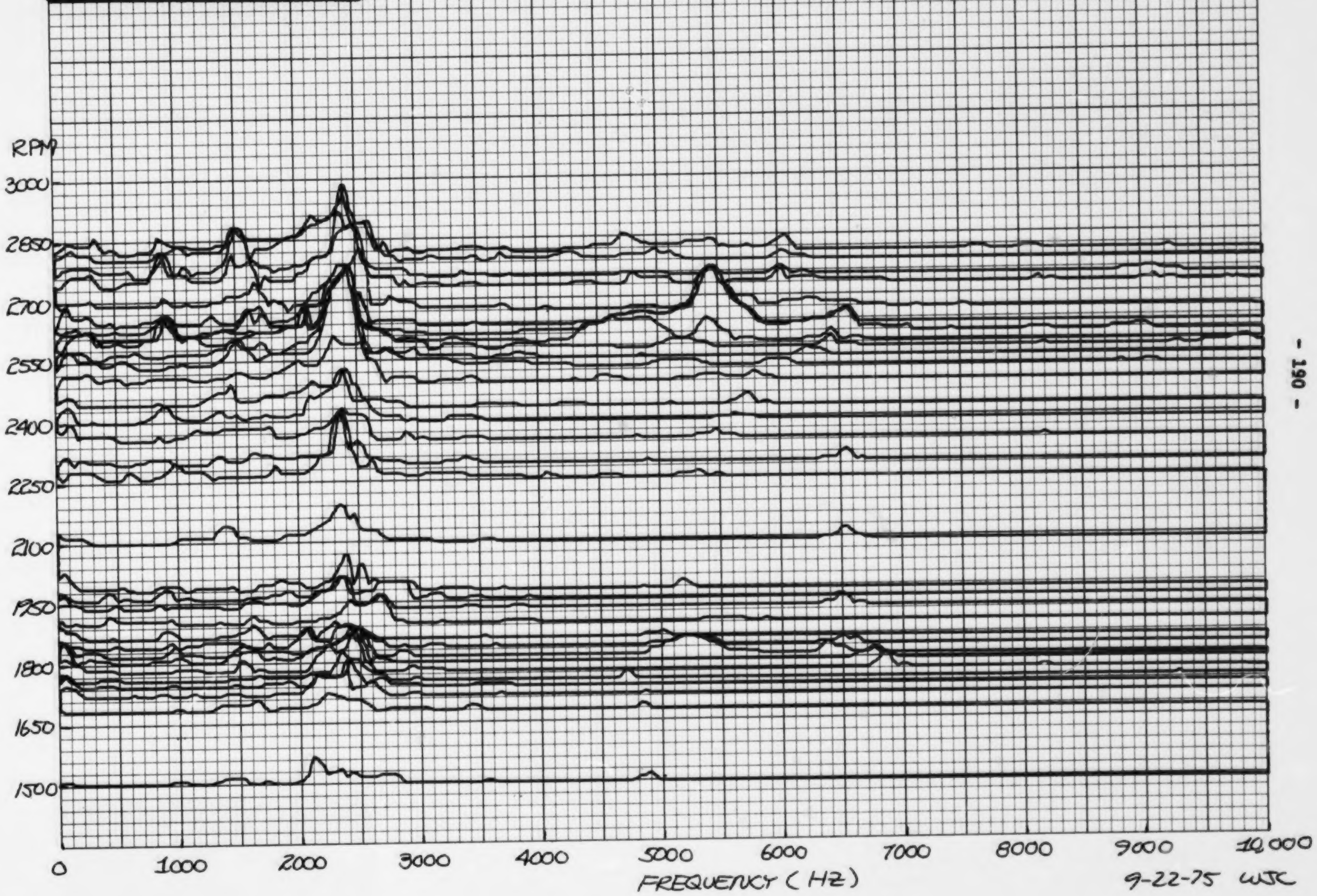


9-22-75 WJC

[redacted]

#8-5

Acceleration Test - 78 Octane Fuel
Accelerometer #5 - R.F. Cylinder Head
Vert.
1700 to 2900 RPM

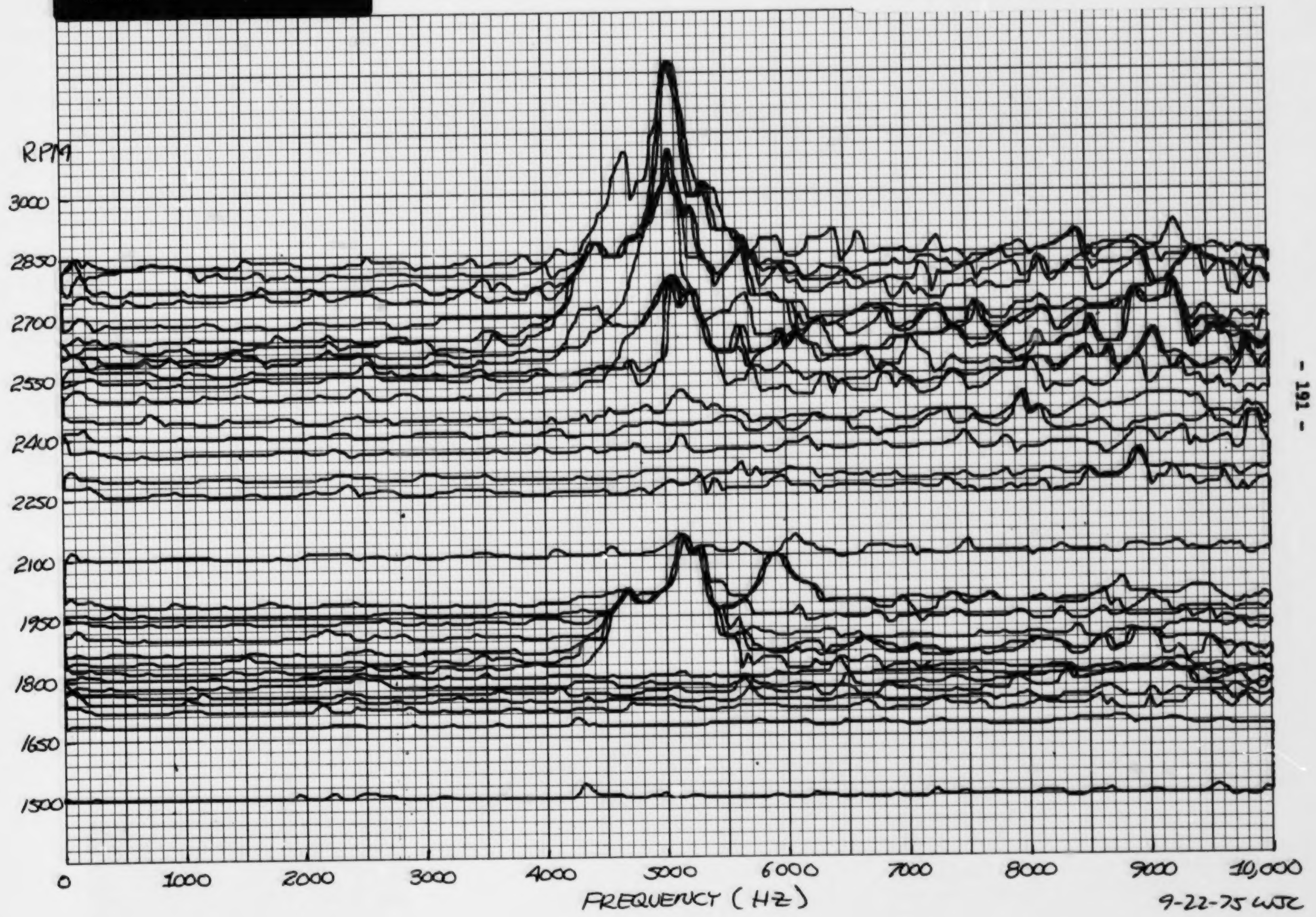


9-22-75 WJC

[redacted]

#8-6

Acceleration Test - 78 Octane Fuel
Accelerometer #6 - R.R. Cylinder Head
Hor.
1700 to 2900 RPM

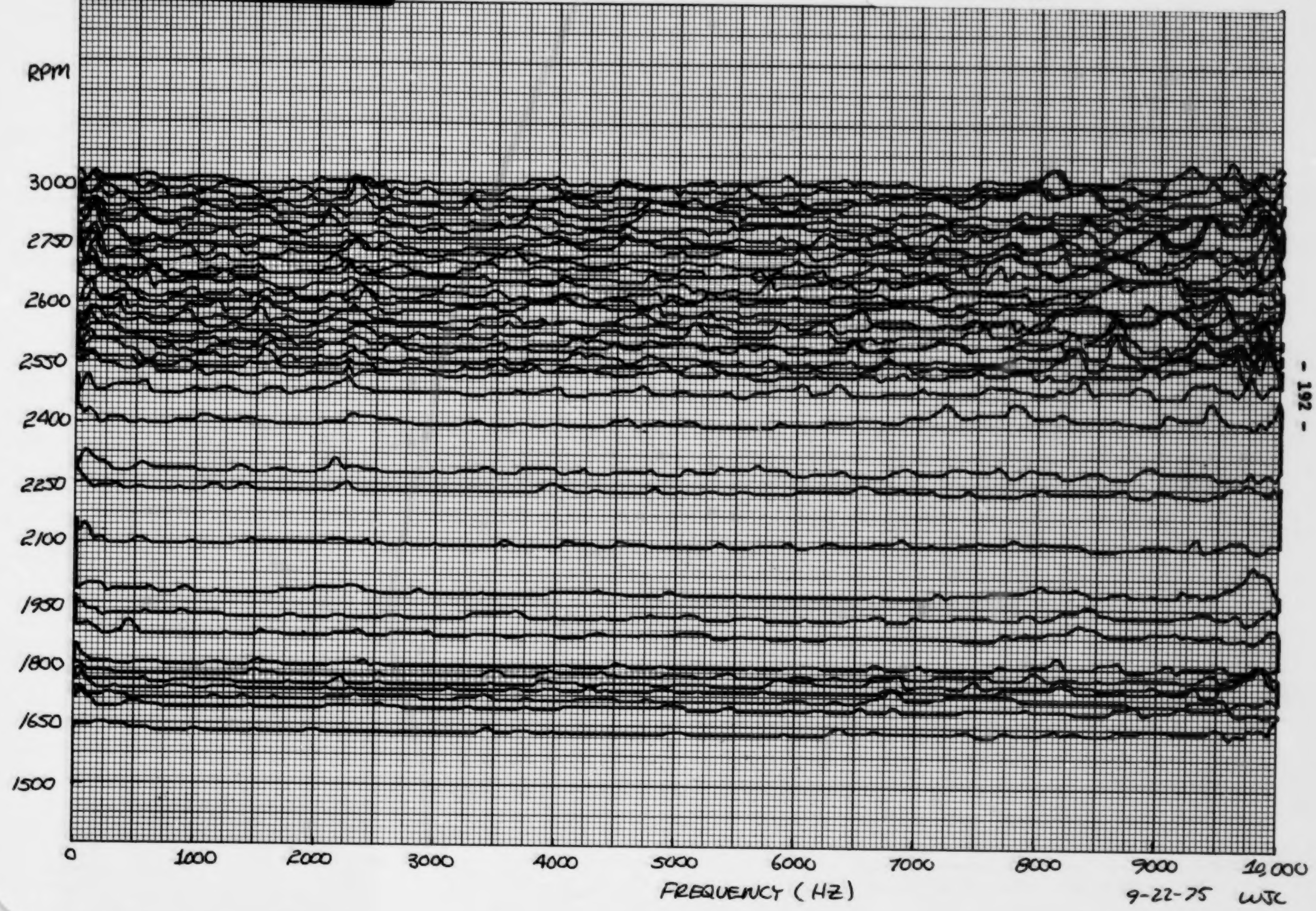


9-22-75 WJC

[redacted]

#9-1

Acceleration Test - House Fuel
Accelerometer #1 - L.F. Cylinder Head
Vert.
1700 to 2800 RPM
No Knock Detected

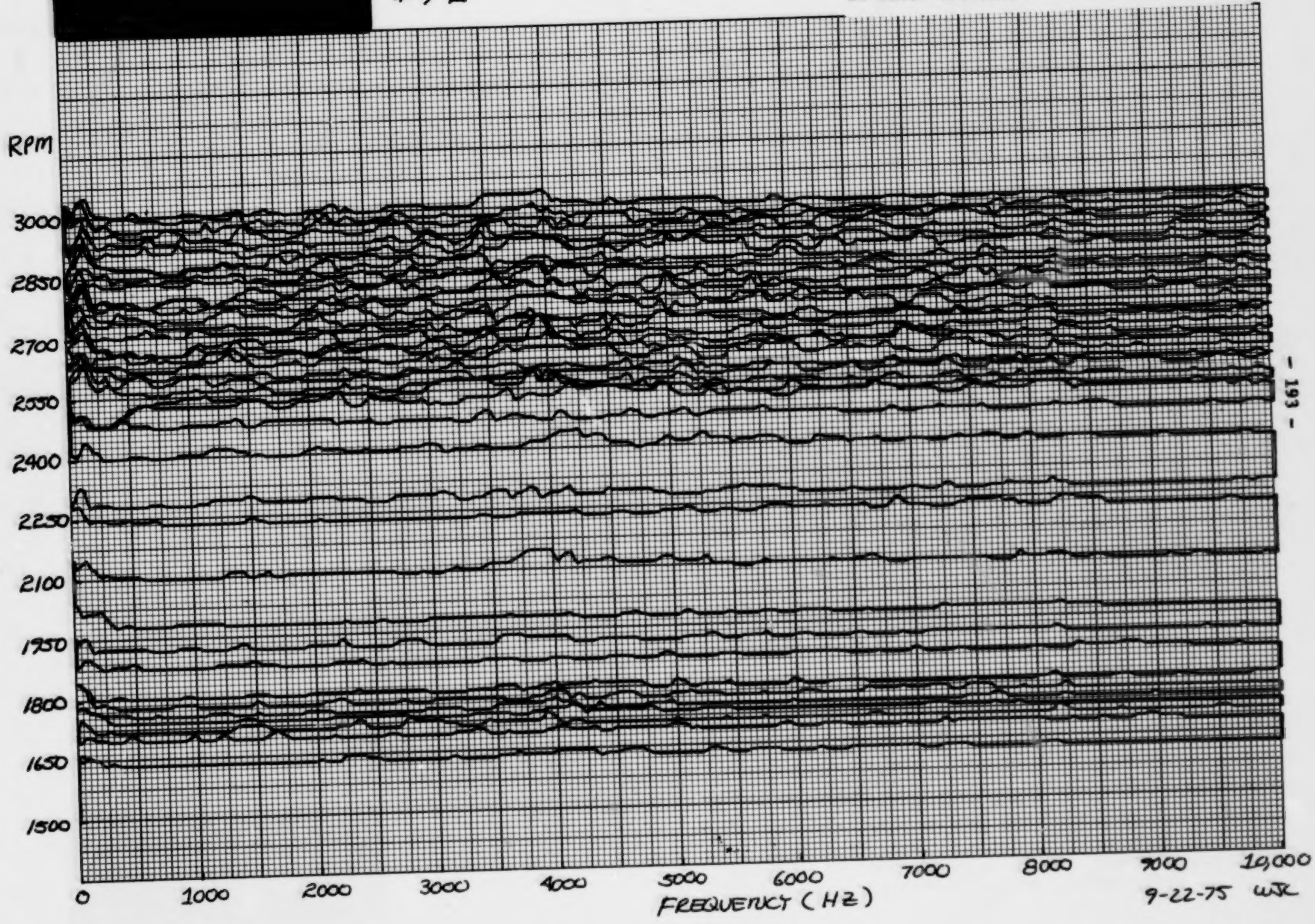


9-22-75 WJC

[redacted]

#9-2

Acceleration Test - House Fuel
Accelerometer #2 - L.R. Cylinder Head
Vert.
1700 to 2800 RPM
No Knock Detected

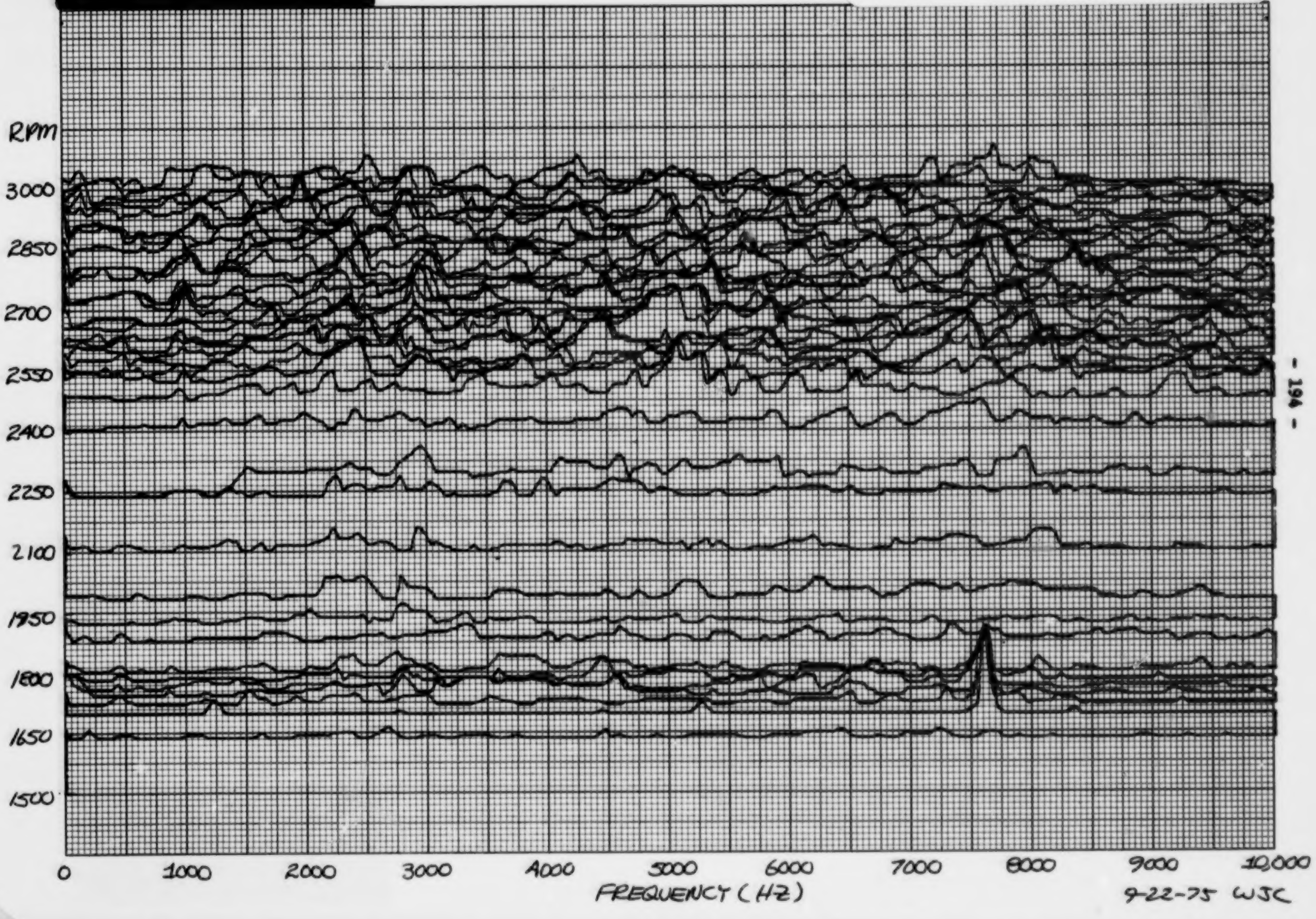


9-22-75 wJK

[redacted]

#9-3

Acceleration Test - House Fuel
Accelerometer #3 - R. Intake Manifold
Vert.
1700 to 2800 RPM
No Knock Detected

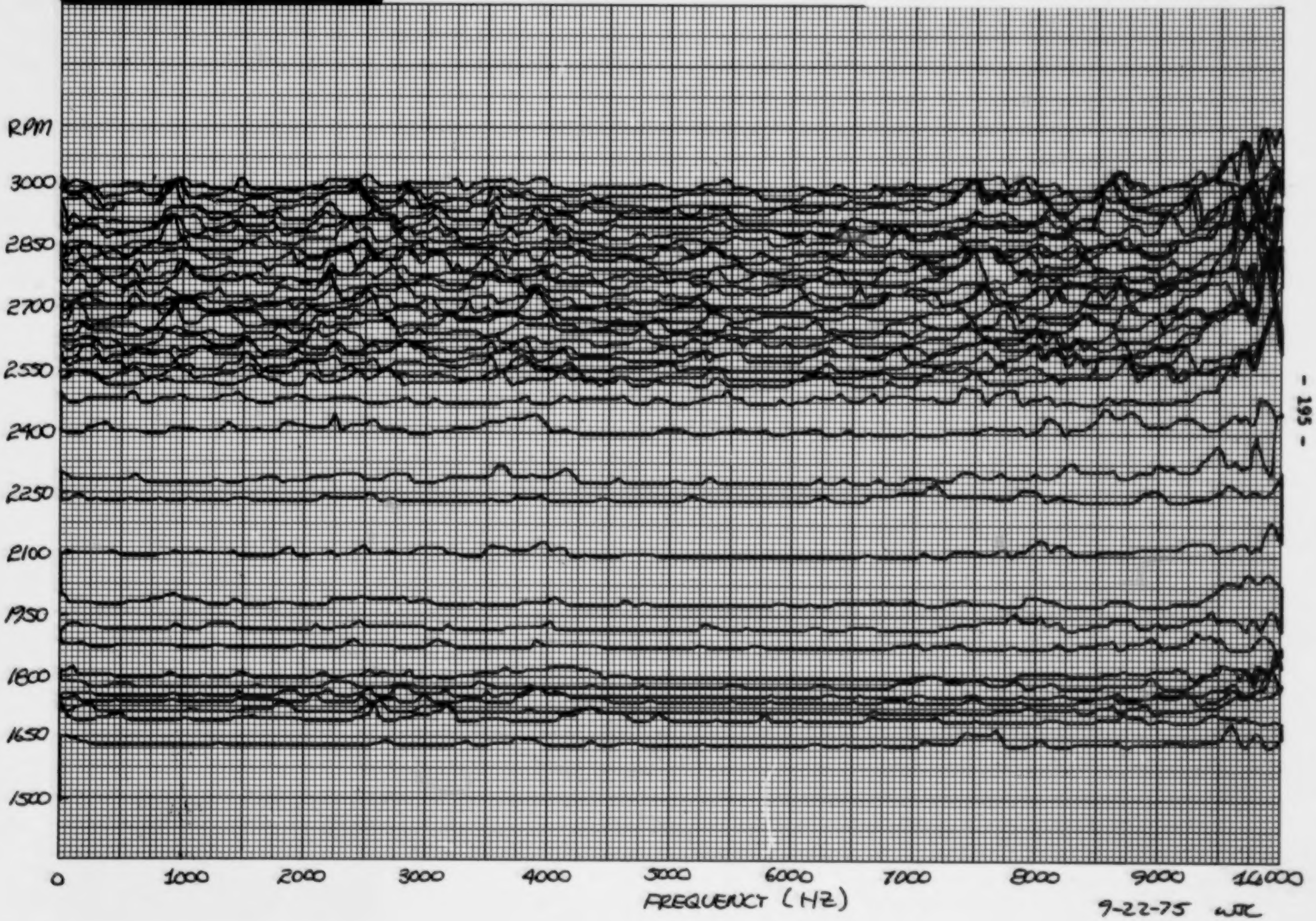


9-22-75 WJC

[redacted]

#9-4

Acceleration Test - House Fuel
Accelerometer #4 - F. Intake Manifold
Vert.
1700 to 2800 RPM
No Knock Detected

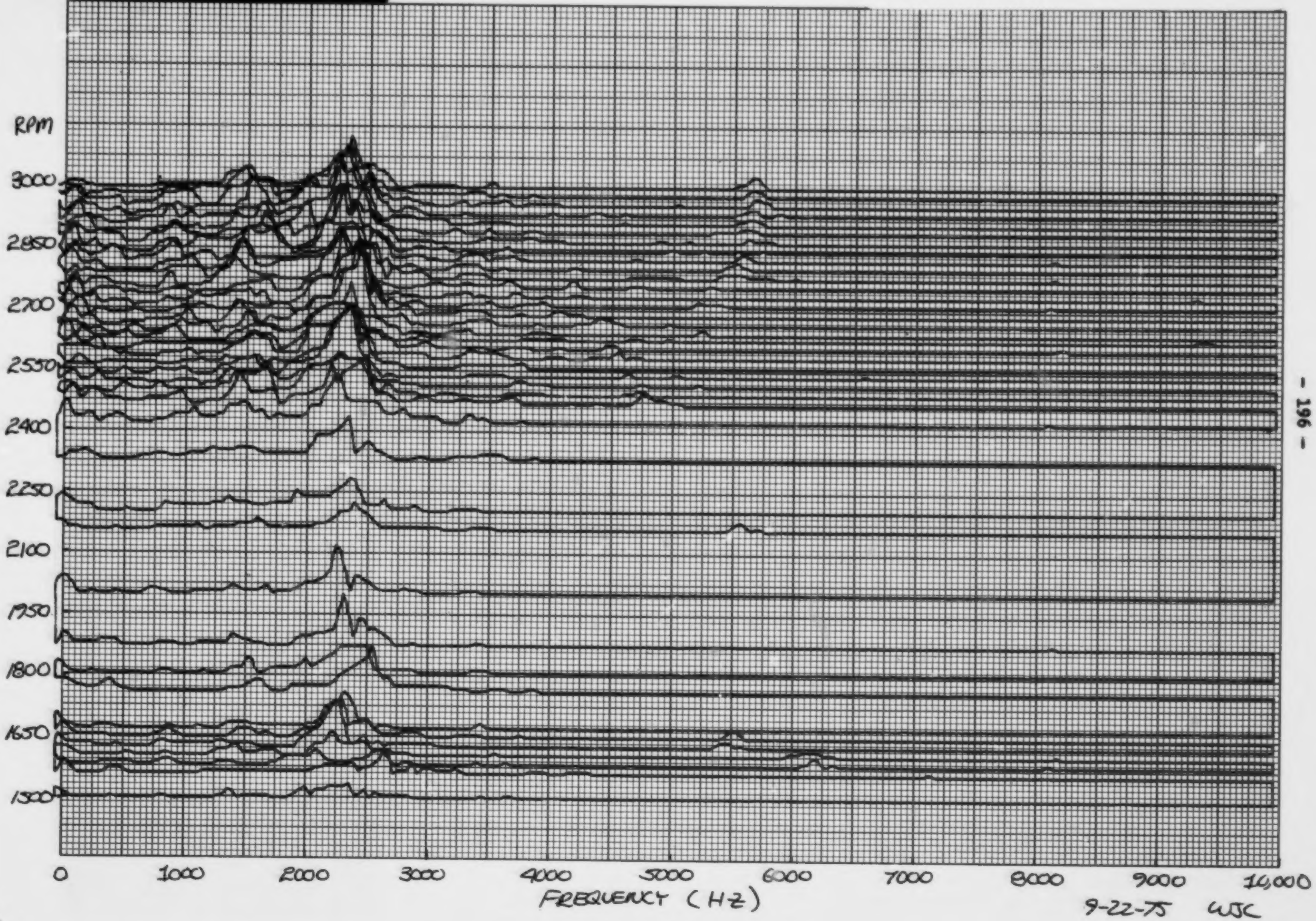


9-22-75 wjc

[redacted]

#9-5

Acceleration Test - House Fuel
Accelerometer #5 - R.F. Cylinder Head
Vert.
1700 to 2800 RPM
No Knock Detected

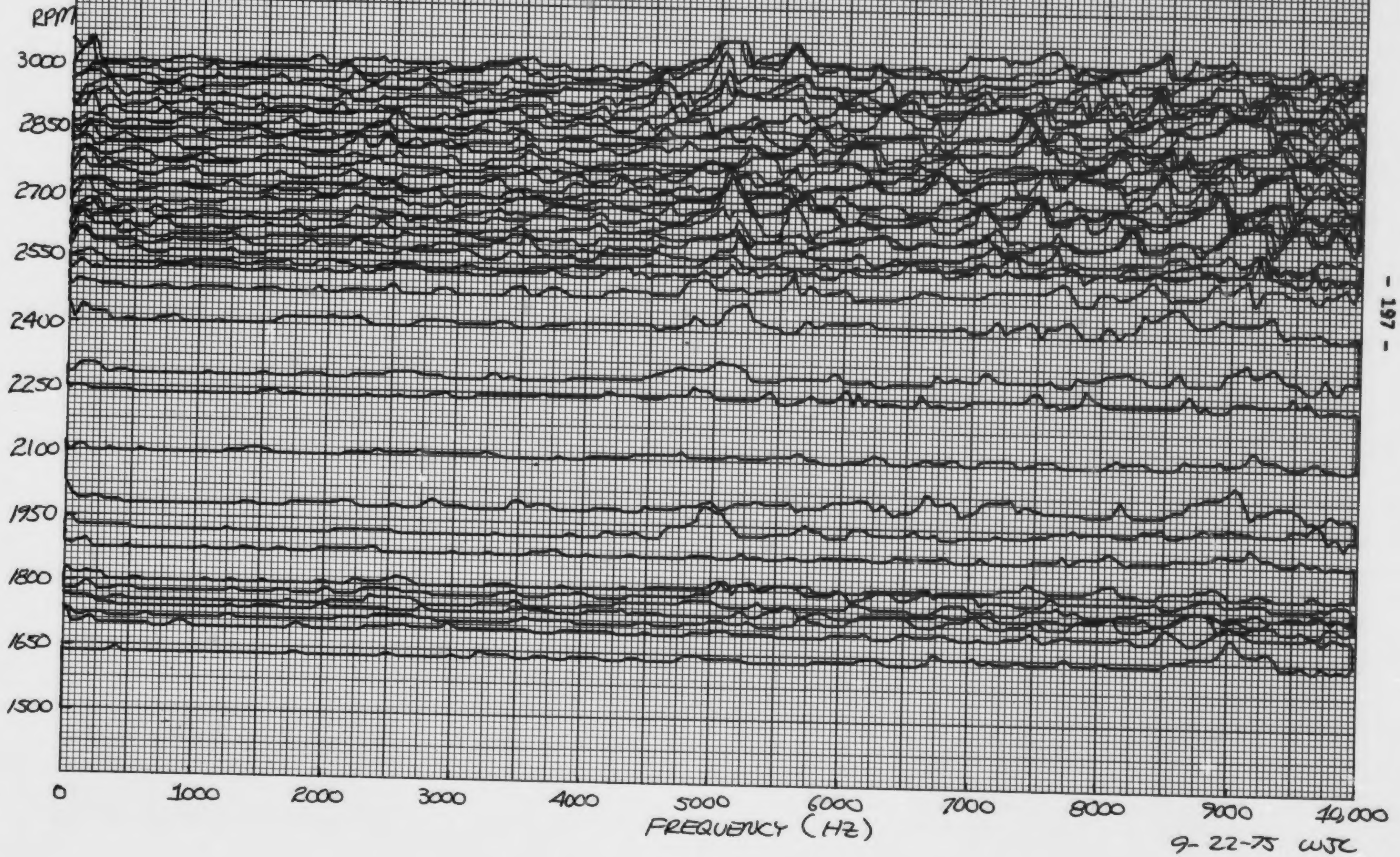


9-22-75 WJC

[redacted]

#9-6

Acceleration Test - House Fuel
Accelerometer #6 - R.R. Cylinder Head
Hor.
1700 to 2800 RPM
No Knock Detected

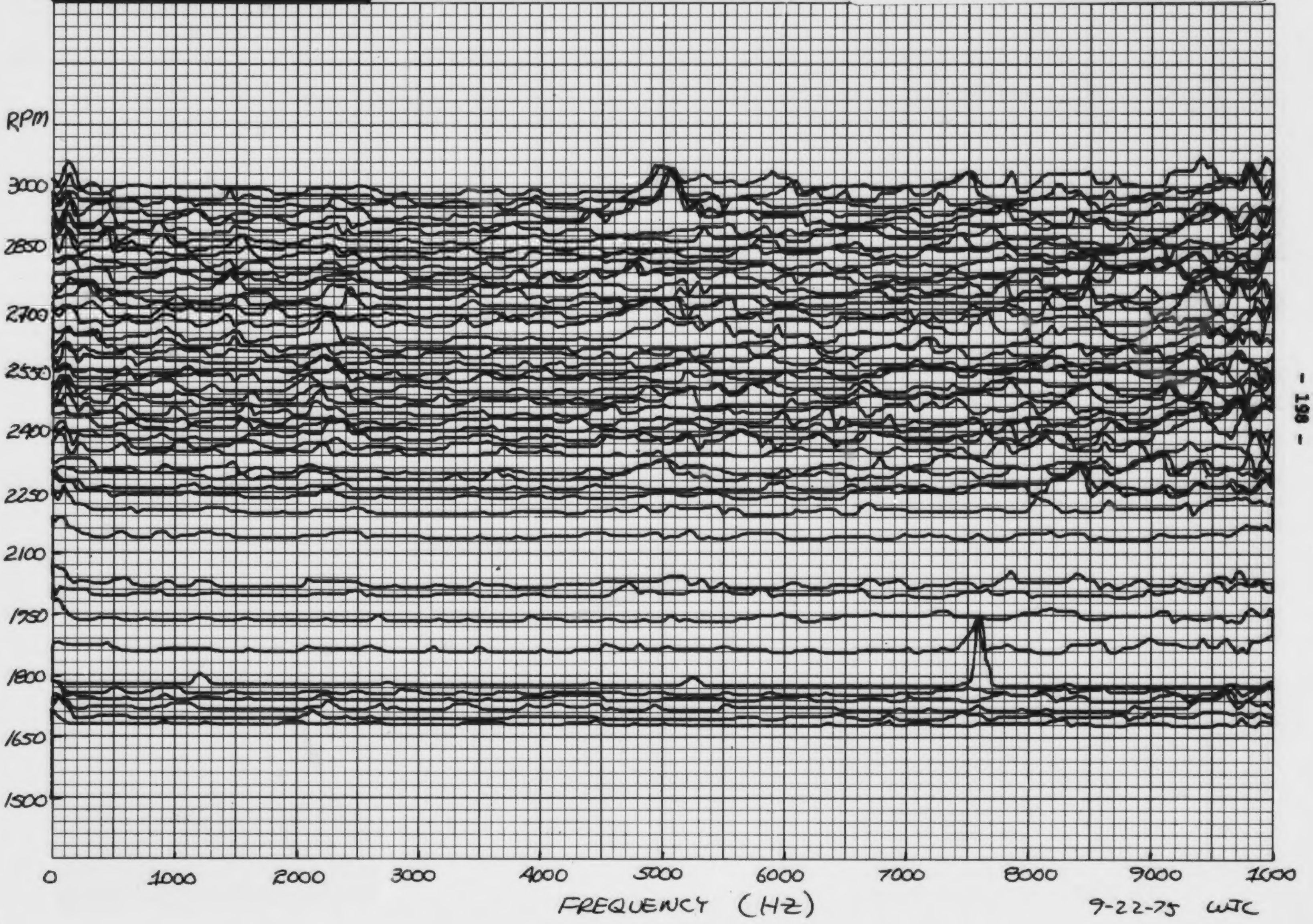


9-22-75 WJC

[redacted]

#10-1

Acceleration Test - 82 Octane Fuel
Accelerometer #1 - L.F. Cylinder Head
Vert.
1750 to 3000 RPM
No Knock To Very Light Knock

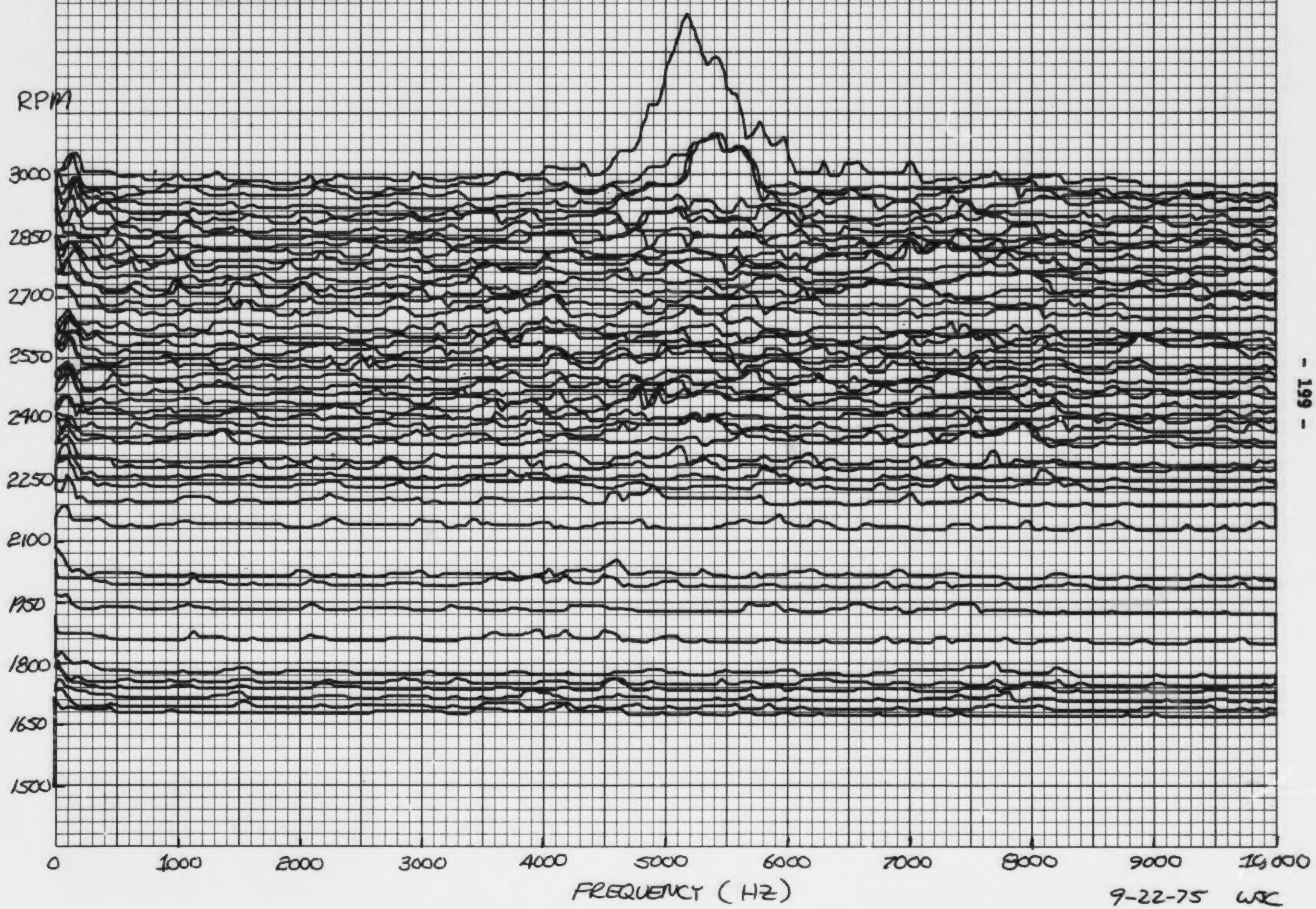


9-22-75 WJC

[redacted]

#10-2

Acceleration Test - 82 Octane Fuel
Accelerometer #2 - L.R. Cylinder Head
  Vert.
1750 to 3000 RPM
No Knock To Very Light Knock

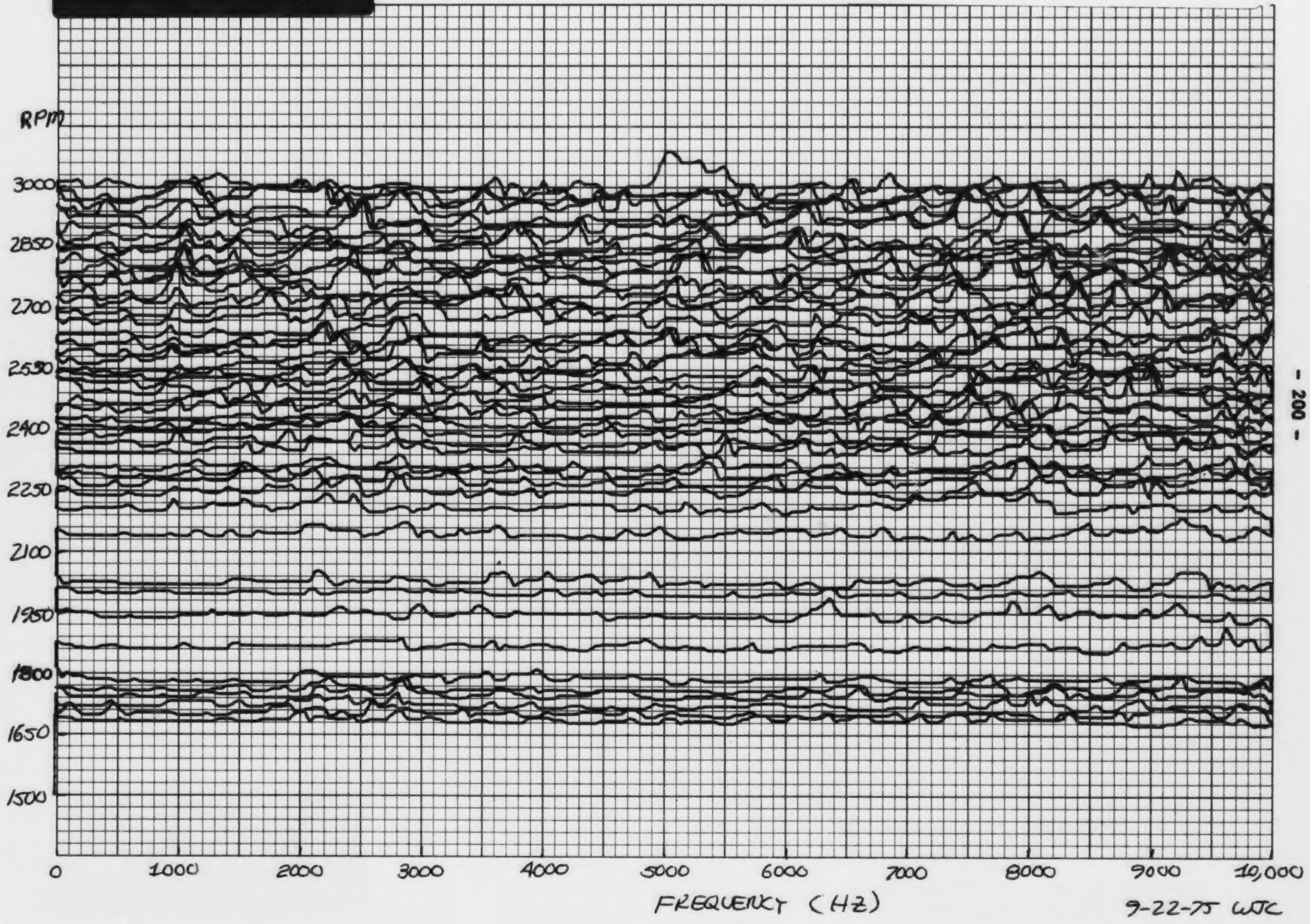


9-22-75 WRC

[redacted]

#10-3

Acceleration Test - 82 Octane Fuel
Accelerometer #3 - R. Intake Manifold
Vert.
1750 to 3000 RPM
To Knock To Very Light Knock

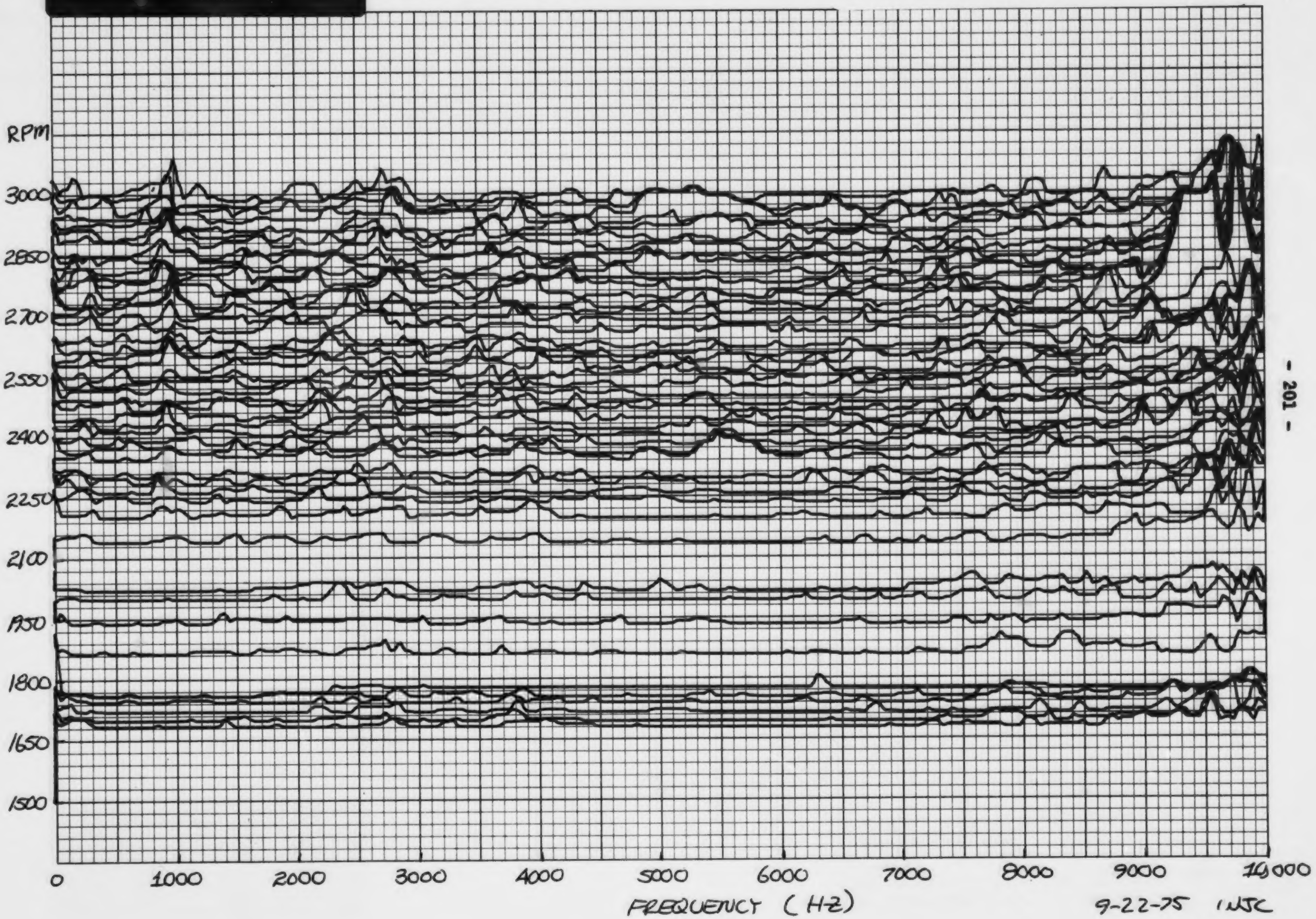


9-22-75 WJC

[redacted]

#10-4

Acceleration Test - 82 Octane Fuel
Accelerometer #4 - F. Intake Manifold
  Vert.
1750 to 3000 RPM
To Knock To Very Light Knock

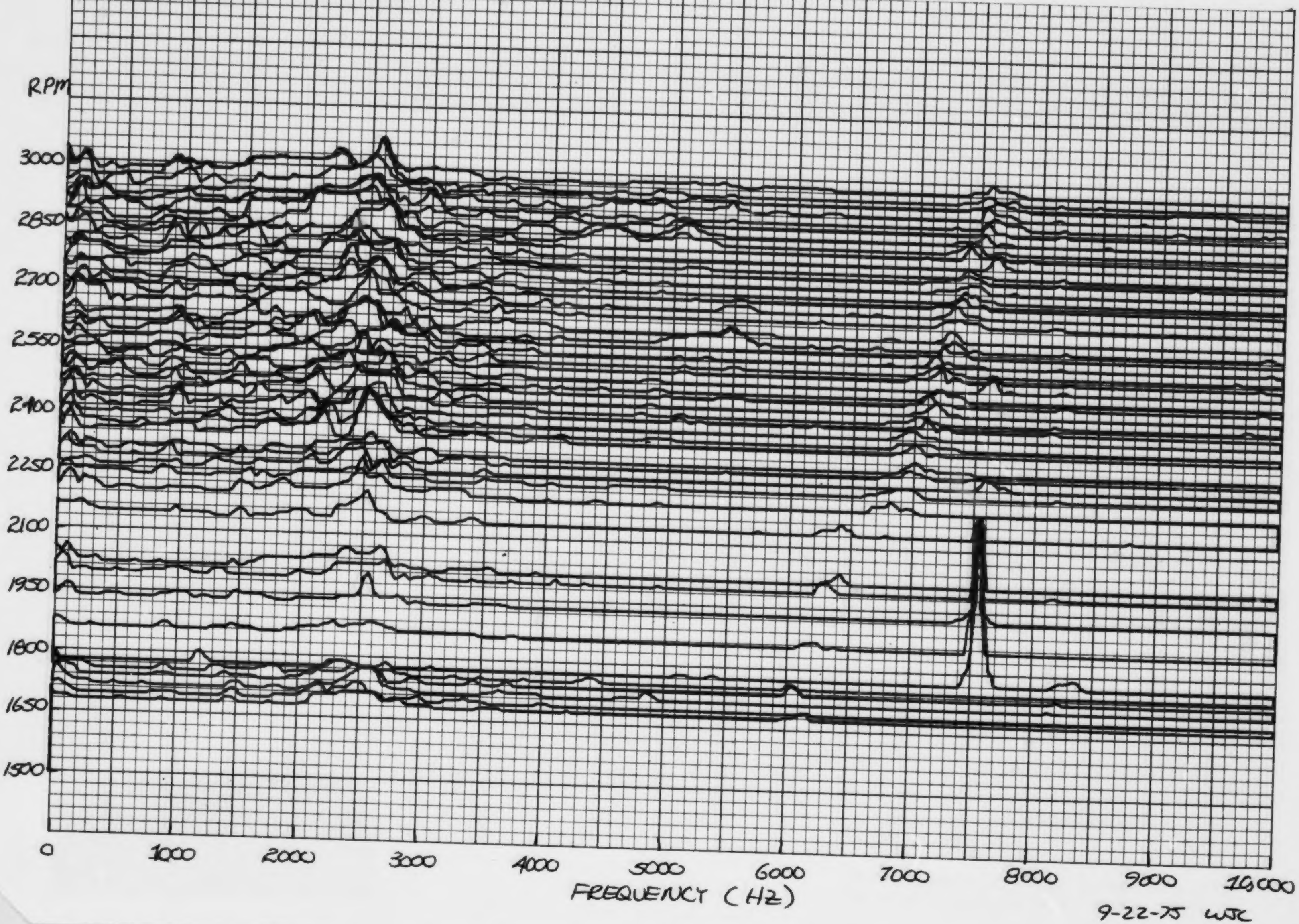


9-22-75 INJC

[redacted]

#10-5

Acceleration Test - 82 Octane Fuel
Accelerometer #5 - R.F. Cylinder Head
Vert.
1250 [illegible]000 RPM
To Knock To Very Light Knock

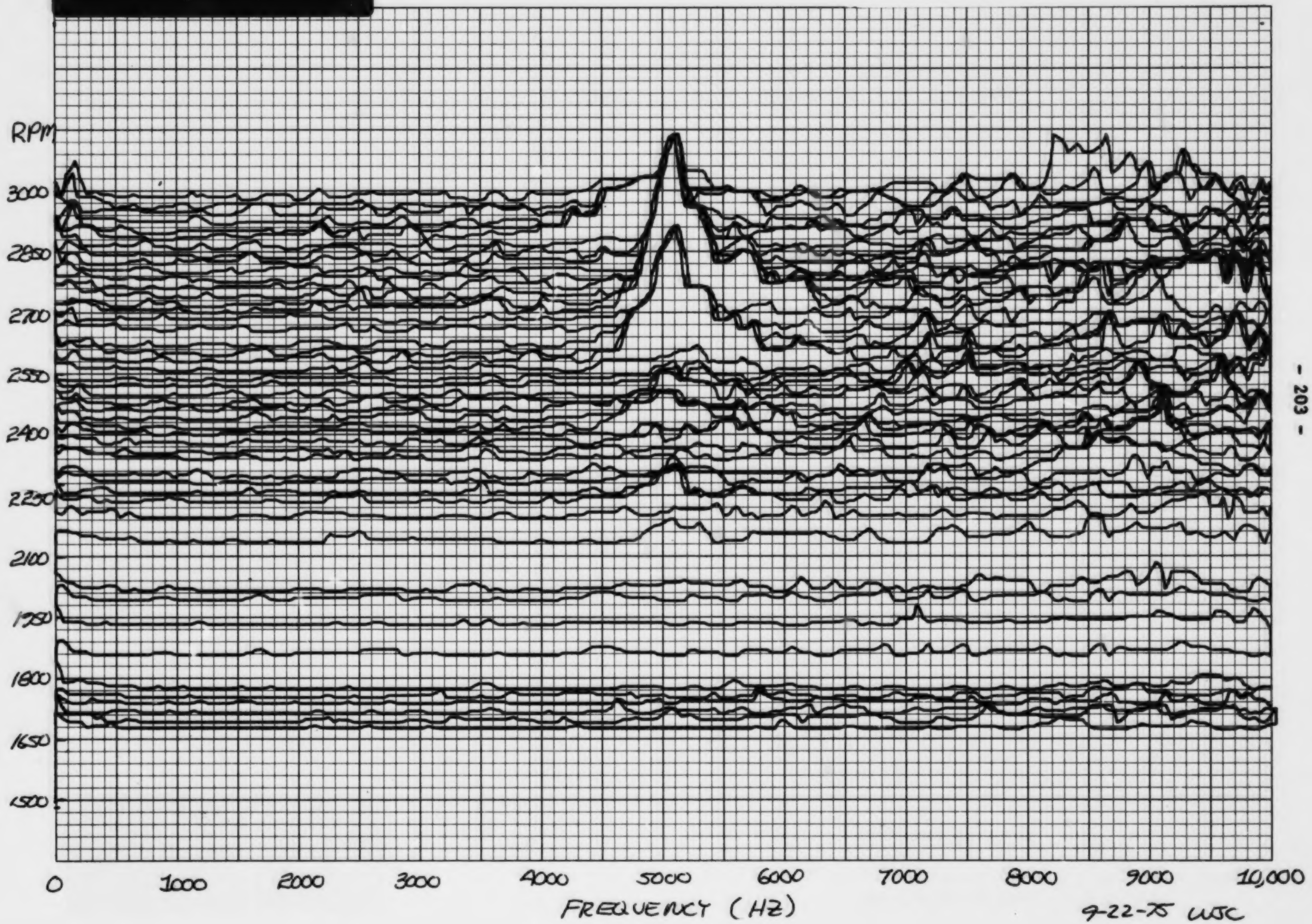


9-22-75 WJC

[redacted]

#10-6

Acceleration Test - 82 Octane Fuel
Accelerometer #6 - R.R. Cylinder Head
Hor.
1750 to 3000 RPM
To Knock To Very Light Knock

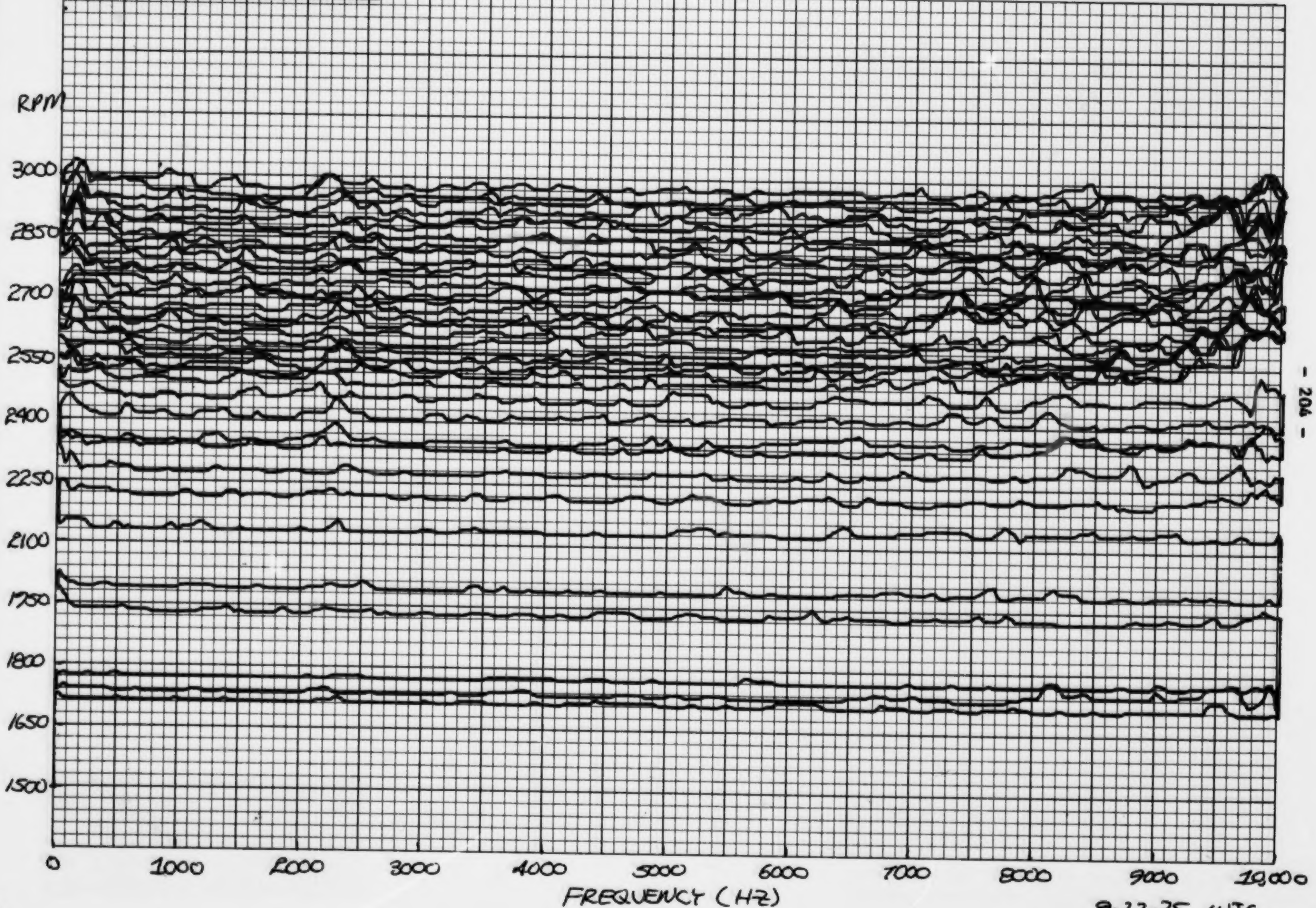


9-22-75 WJC

[redacted]

#11-1

Acceleration Test - House Fuel
Accelerometer #1 - L.F. Cylinder Head
Vert.'
No Knock Detected

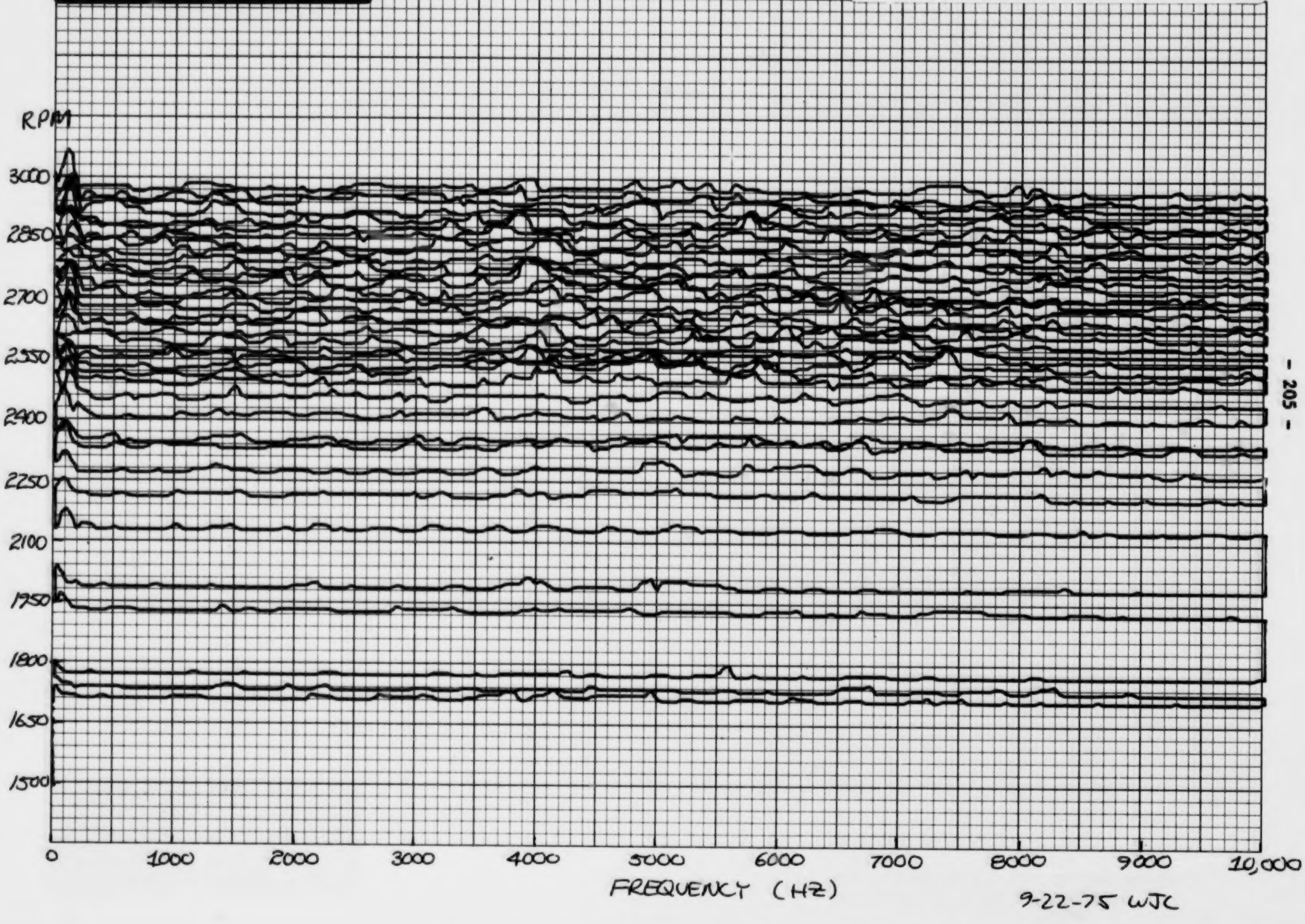


9-22-75 WJC

[redacted]

#11-2

Acceleration Test - House Fuel
Accelerometer #2 - L.R. Cylinder Head
Vert.
No Knock Detected

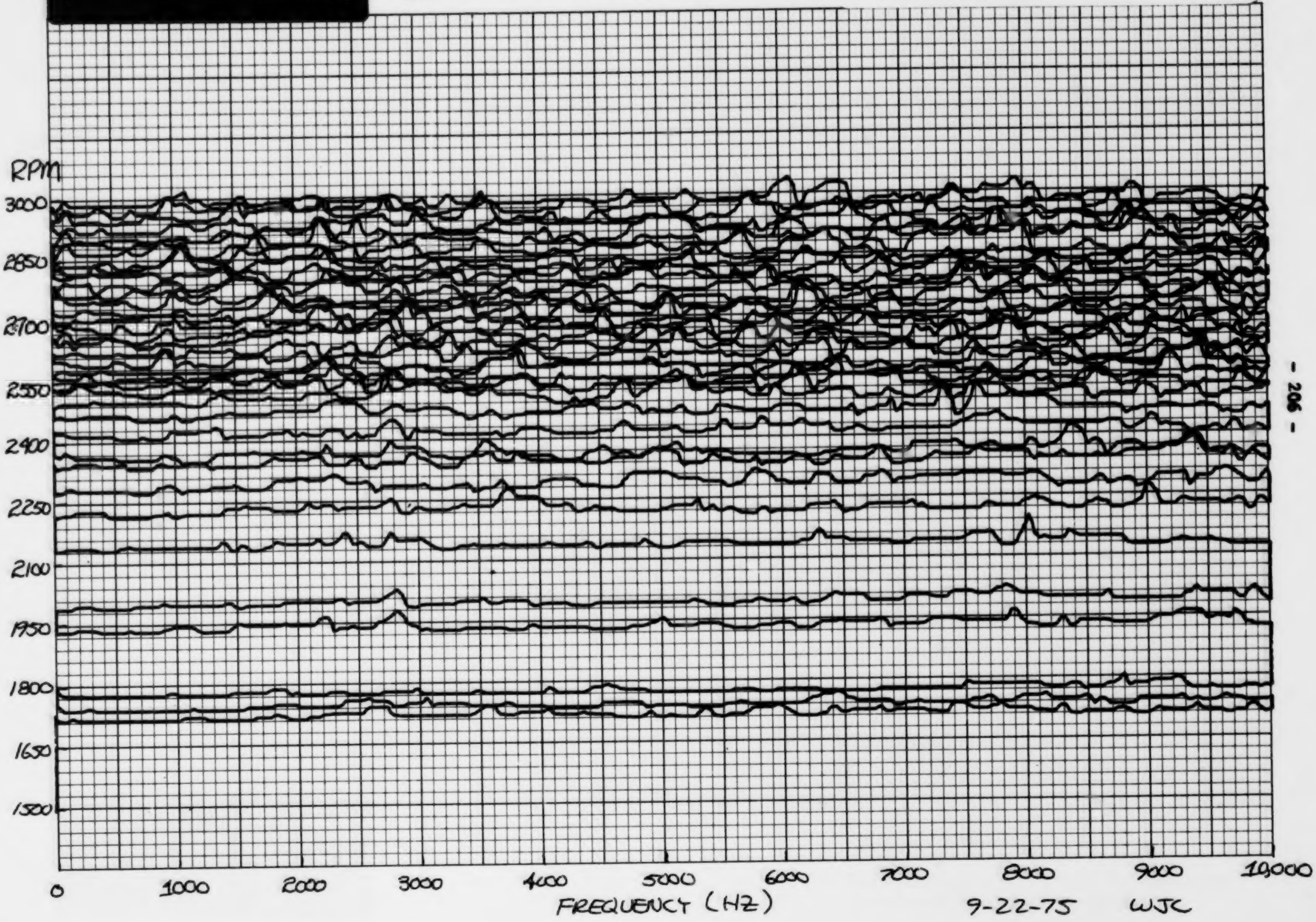


9-22-75 WJC

[redacted]

#11-3

Acceleration Test - House Fuel
Accelerometer #3 - R. Intake Manifold
Vert.
No Knock Detected

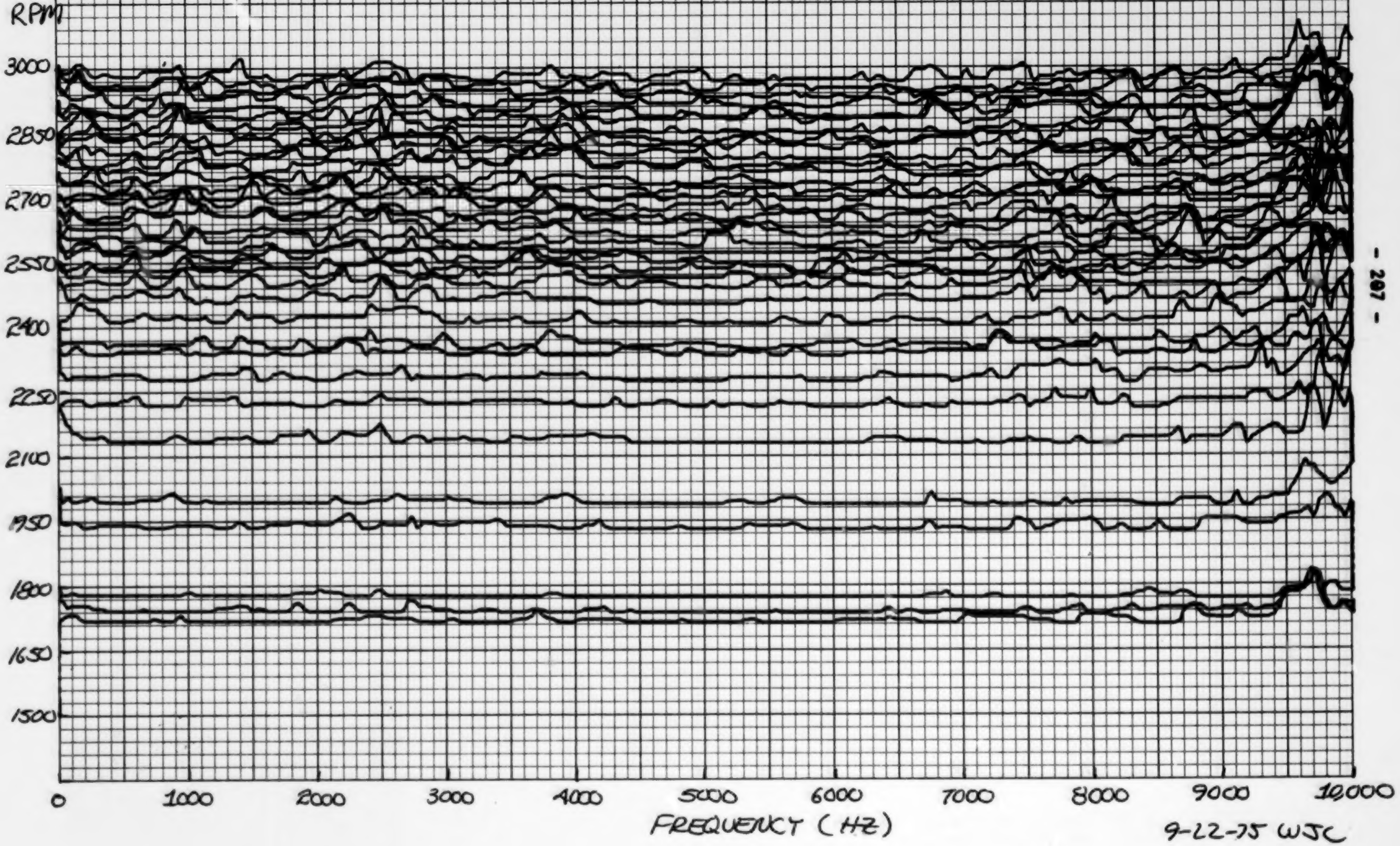


9-22-75 WJC

[redacted]

#11-4

Acceleration Test - House Fuel
Accelerometer #4 - F. Intake Manifold
Vert.
No Knock Detected

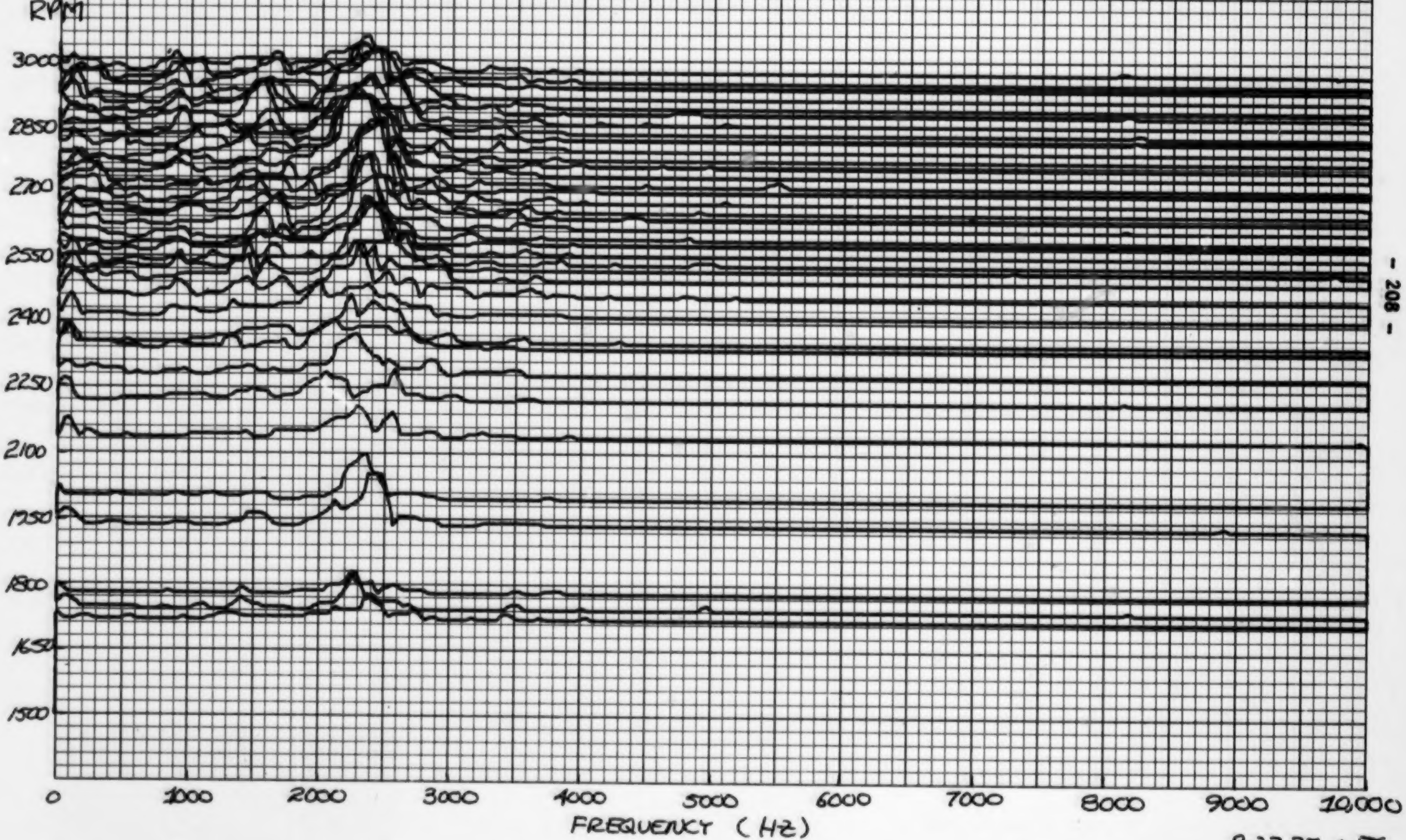


9-22-75 WJC

[redacted]

#11-5

Acceleration Test - House Fuel
Accelerometer #5 - R.F. Cylinder Head
  Vert.
No Knock Detected

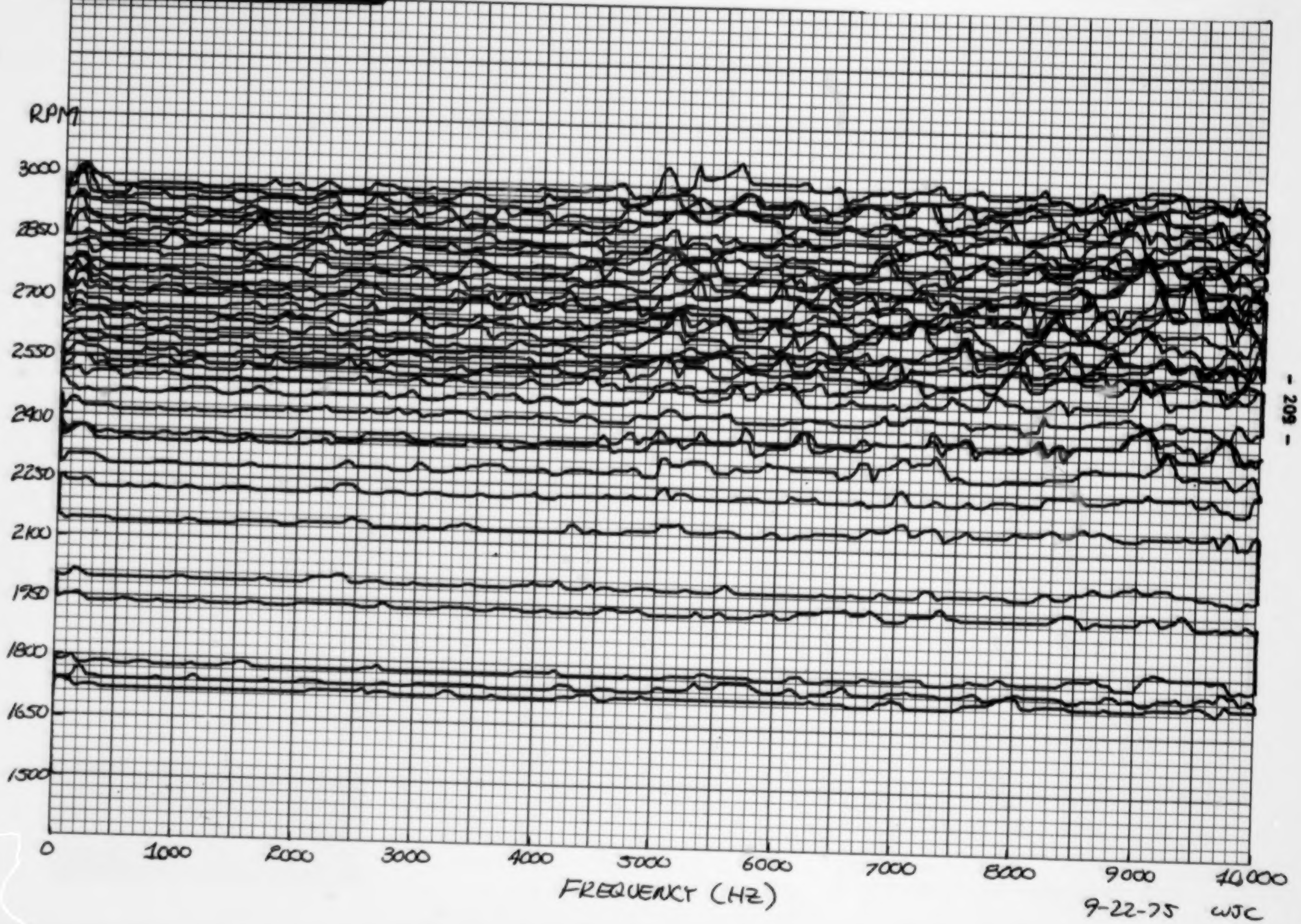


9-22-75 wJC

[redacted]

#11-6

Acceleration Test - House Fuel
Accelerometer #6 - R.R. Cylinder Head
Hor.
No Knock Detected

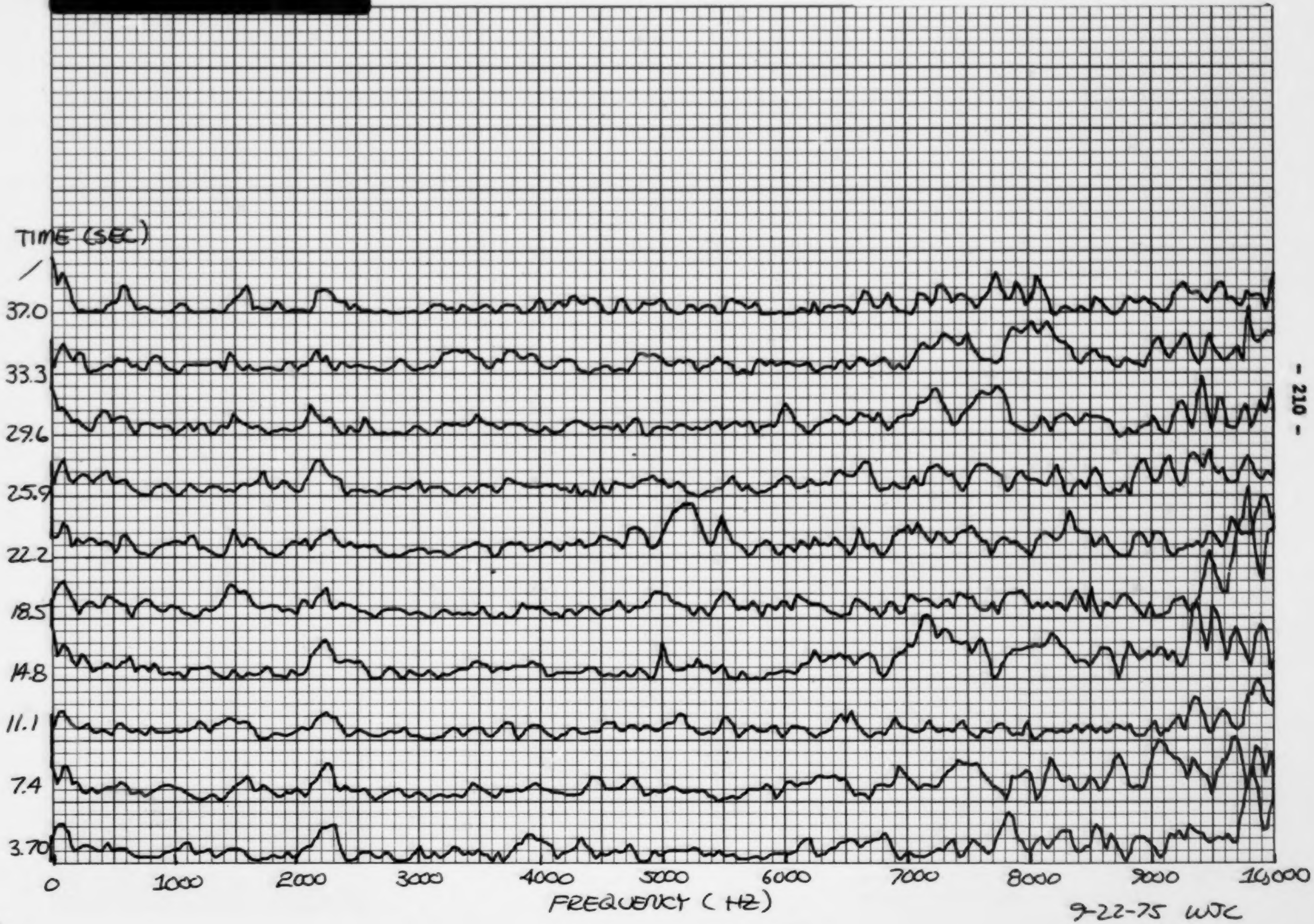


9-22-75 WJC

[redacted]

#12-1

Steady State Test - 82 Octane Fuel
Accelerometer #1 - L.F. Cylinder Head
Vert.
2500 RPM 180 FT LBS Torque 25" HG
Trace Knock Level

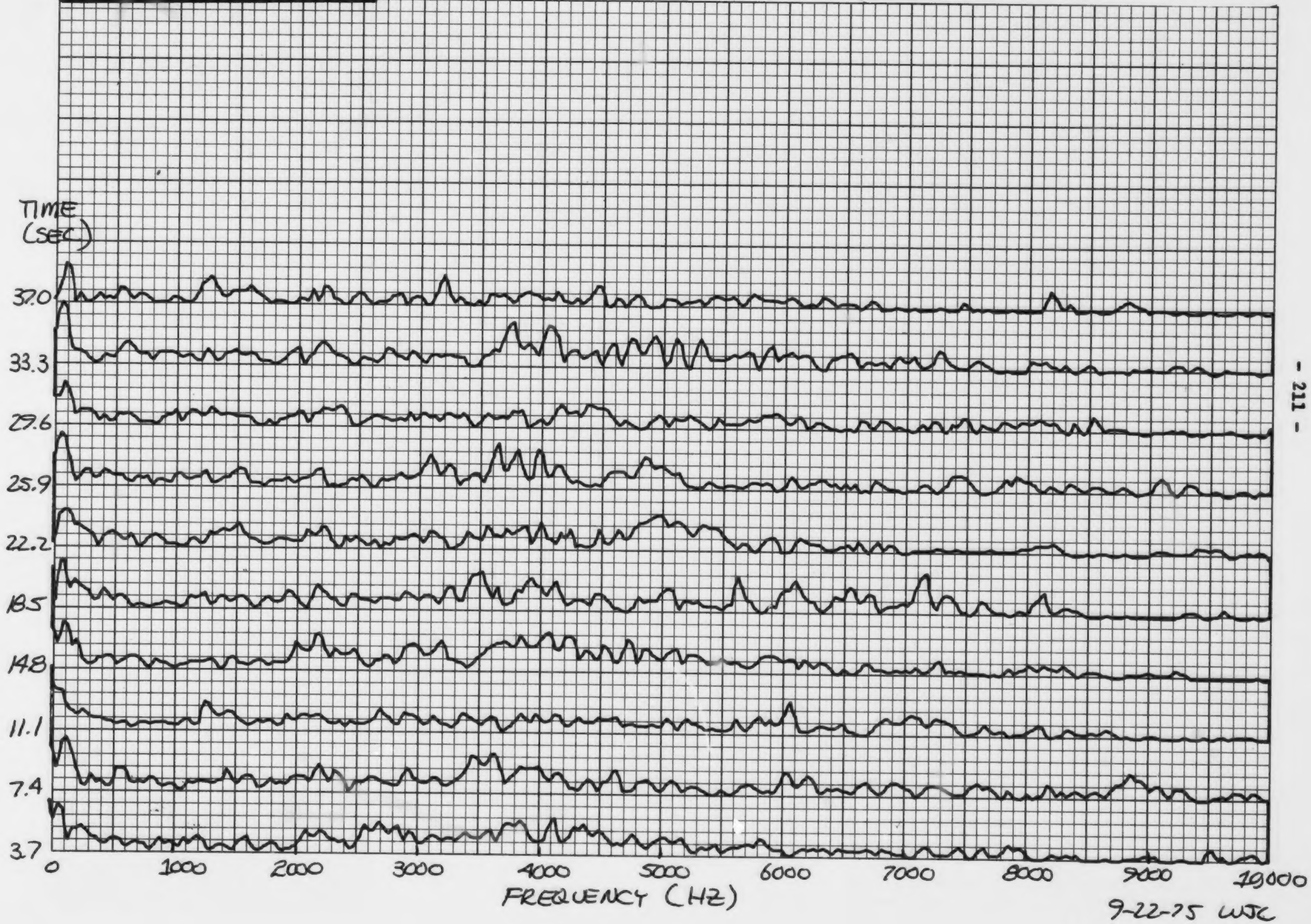


9-22-75 WJC

[redacted]

#12-2

Steady State Test - 82 Octane Fuel
Accelerometer #2 - L.R. Cylinder Head
Vert.
2500 RPM 180 FT LBS Torque 25" HG
Trace Knock Level

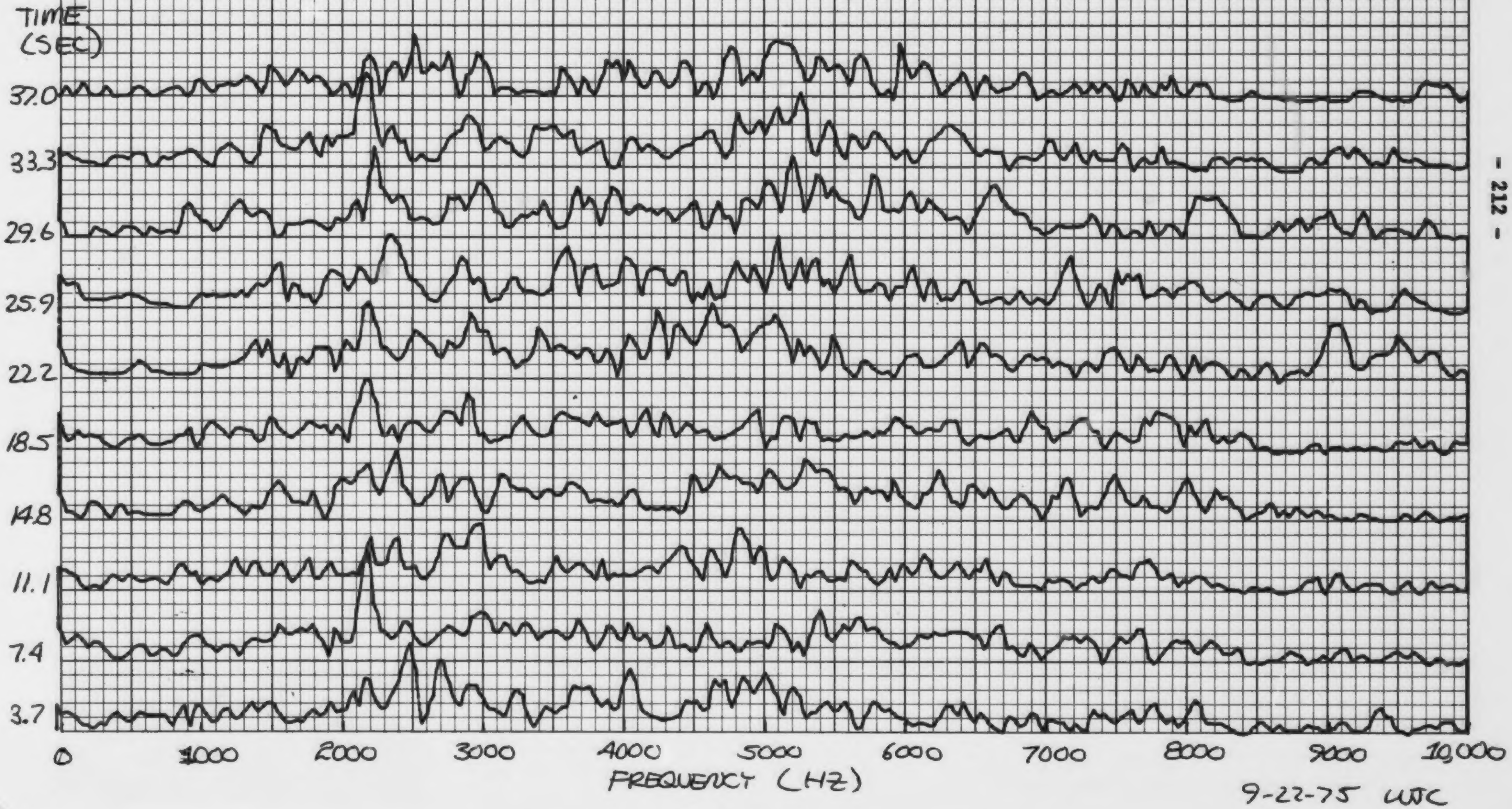


9-22-75 WJC

[redacted]

#12-3

Steady State Test - 82 Octane Fuel
Accelerometer #3 - R. Intake Manifold
Vert.
2500 RPM 180 FT LBS Torque 25" HG
Trace Knock Level

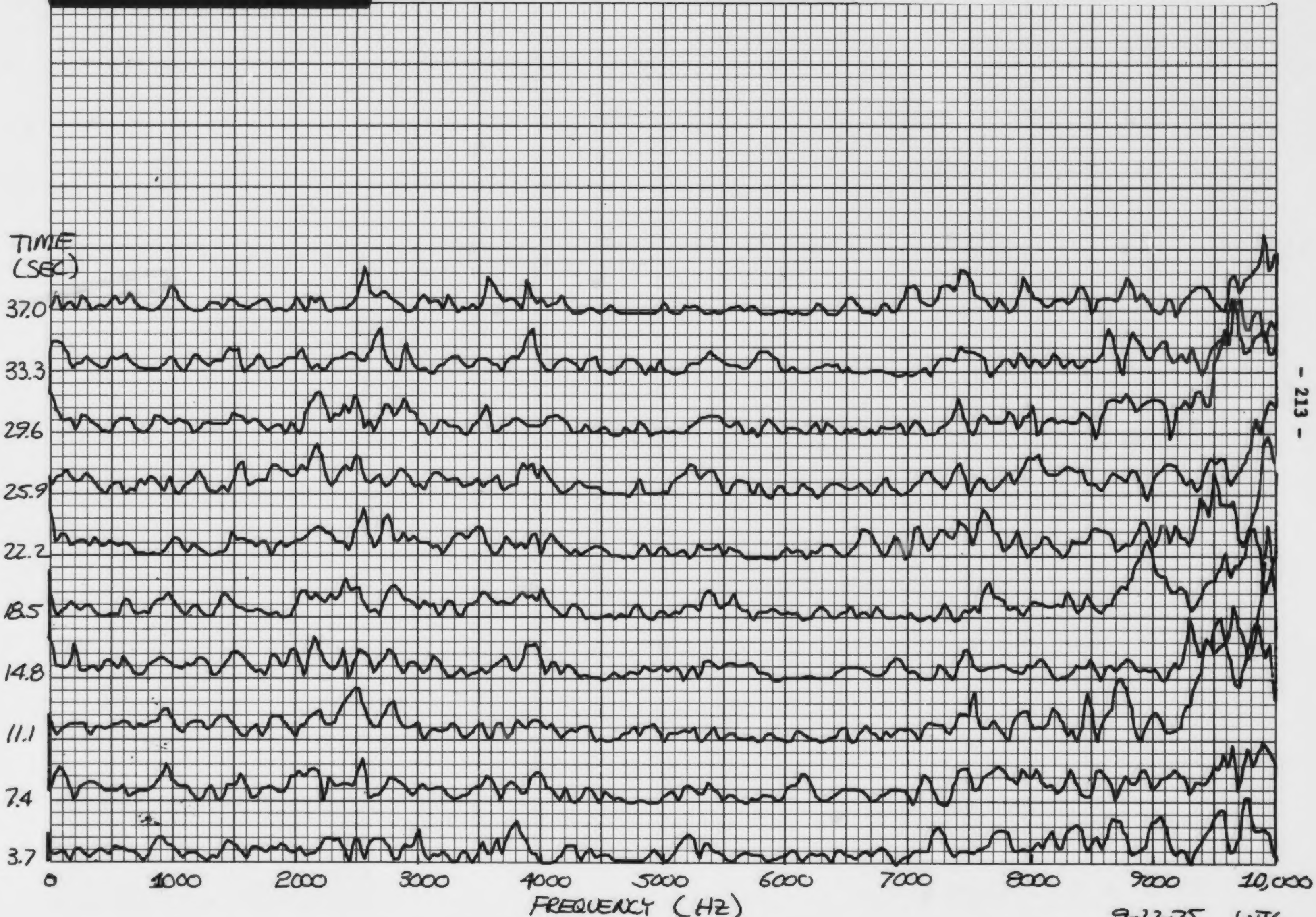


9-22-75 WJC

[redacted]

#12-4

Steady State Test - 82 Octane Fuel
Accelerometer #4 - F. Intake Manifold
Vert.
2500 RPM 180 FT LBS Torque 25" HG
Trace Knock Level

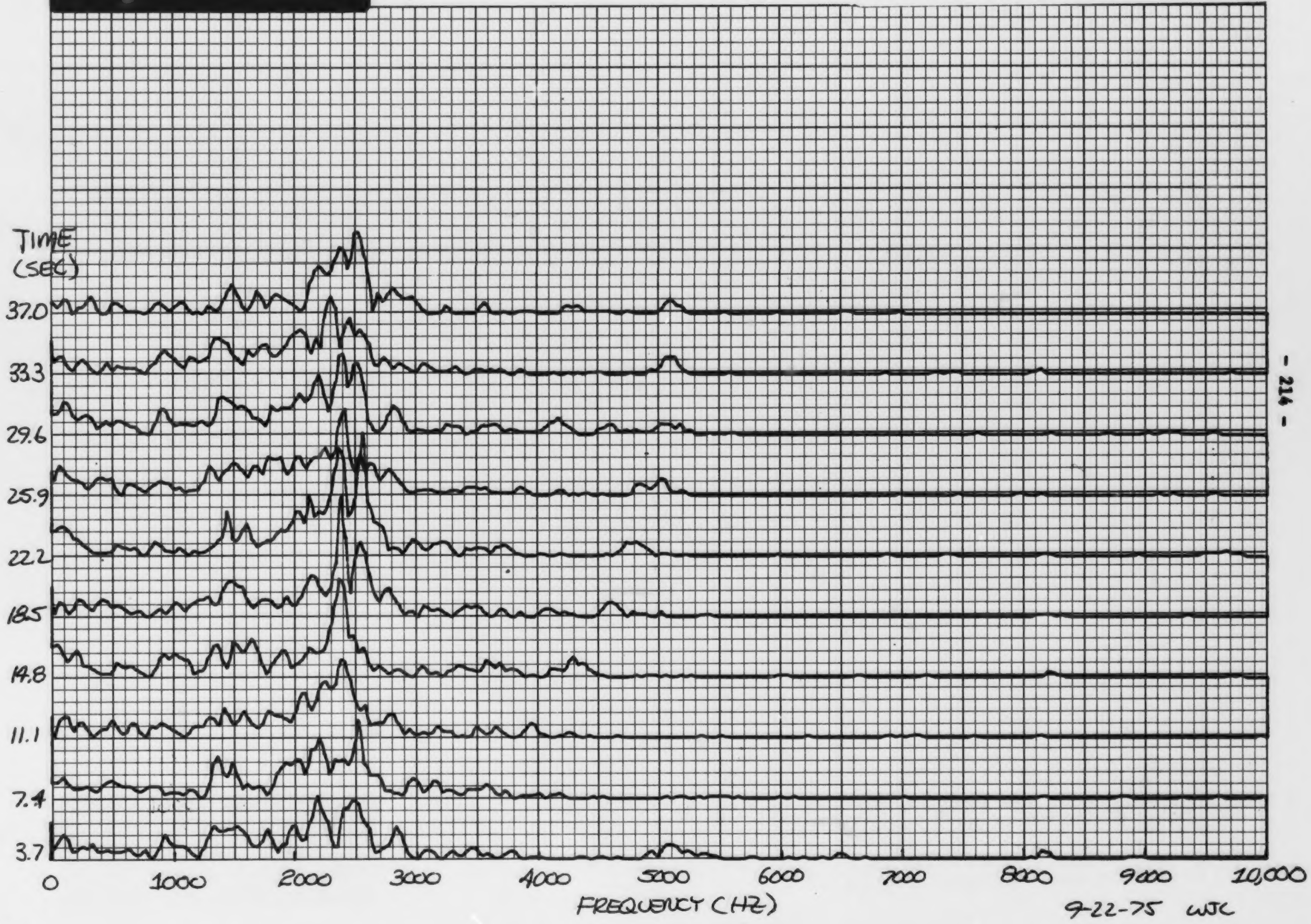


9-22-75 WJC

[redacted]

#12-5

Steady State Test - 82 Octane Fuel
Accelerometer #5 - R.F. Cylinder Head
Vert.
2500 RPM 180 FT LBS Torque 25" HG
Trace Knock Level

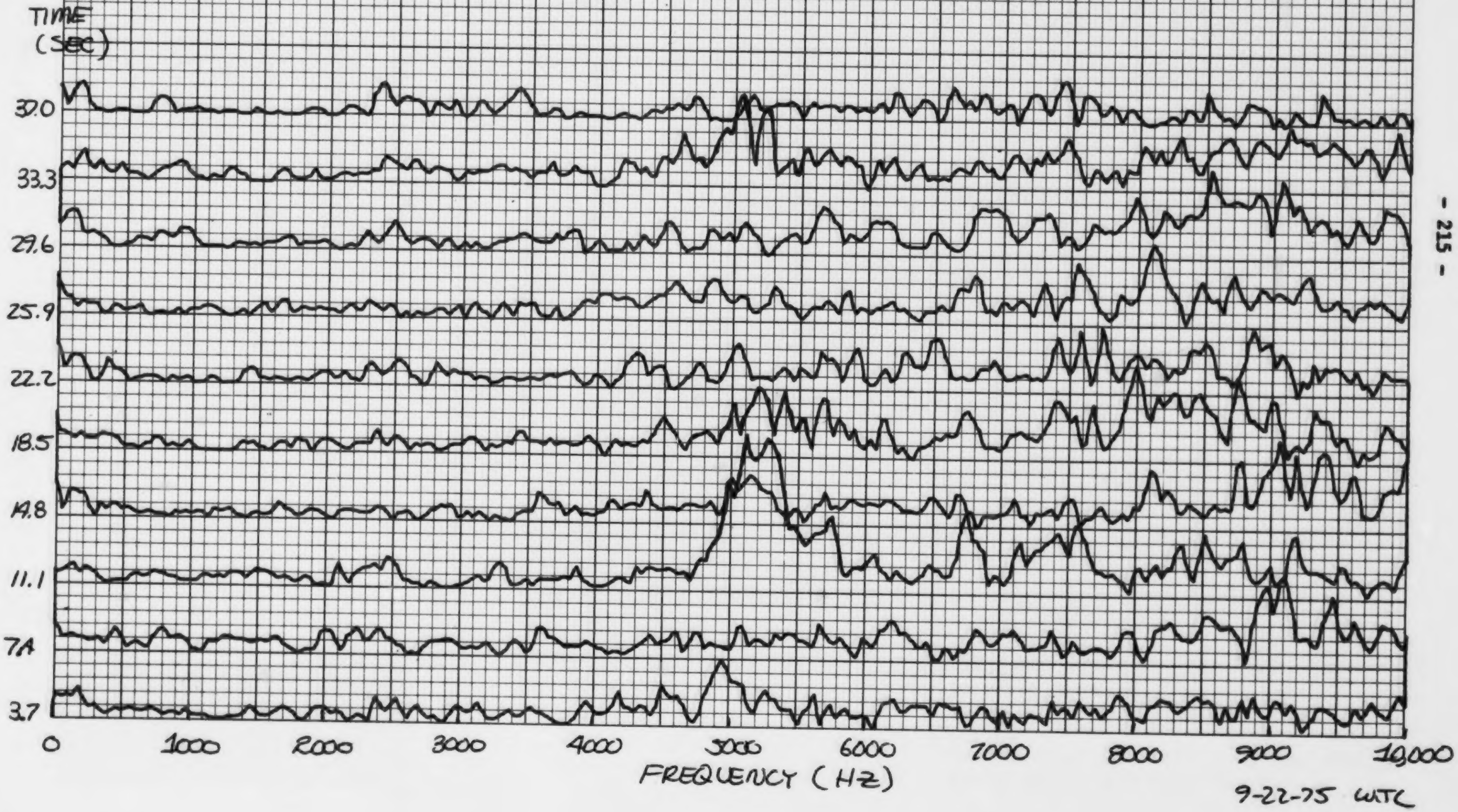


9-22-75 WJC

[redacted]

#12-6

Steady State Test - 82 Octane Fuel
Accelerometer #6 - R.R. Cylinder Head
Hor.
2500 RPM 180 FT LBS Torque 25" HG
Trace Knock Level

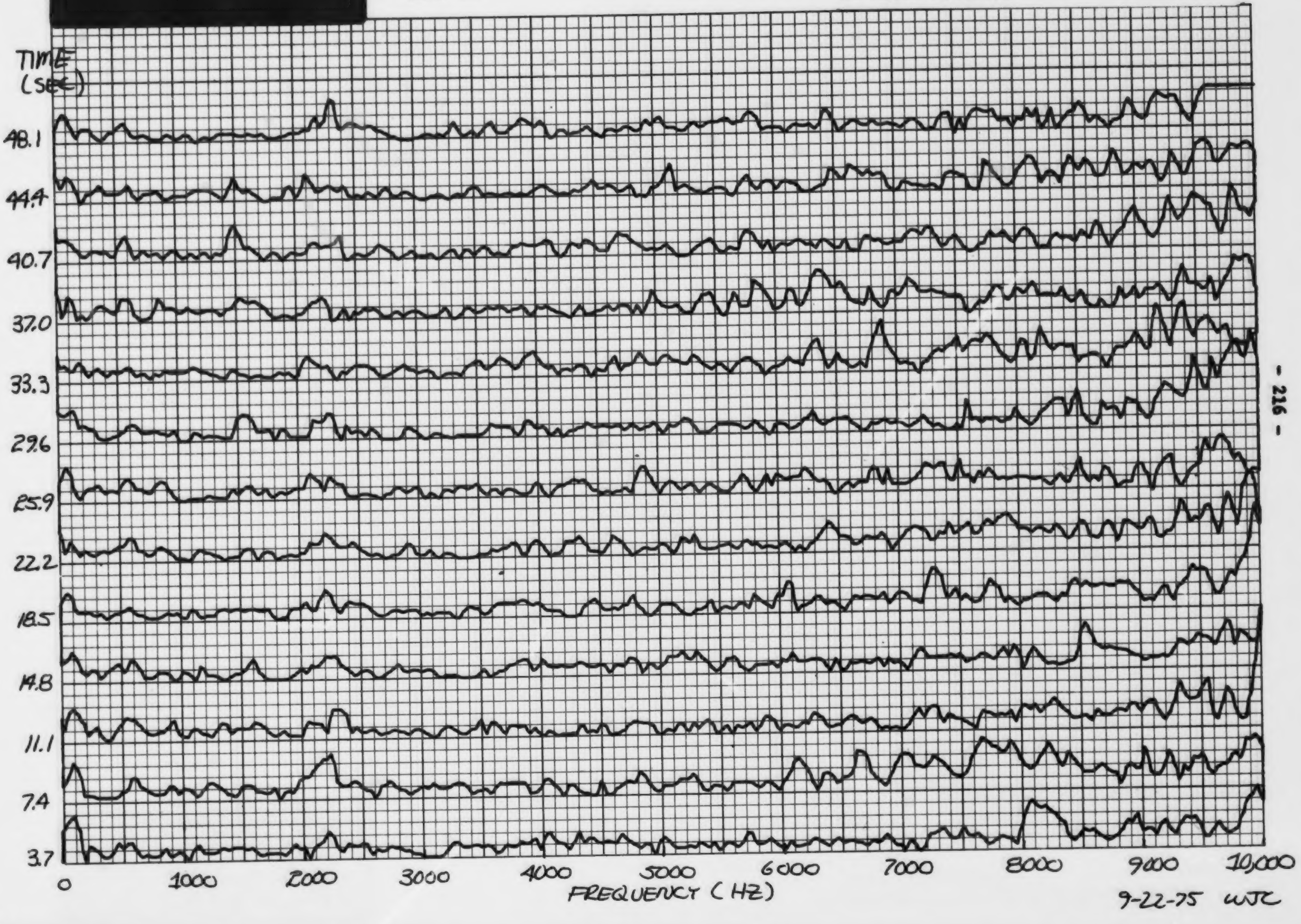


9-22-75 WTC

[redacted]

#13-1

Steady State Test - House Fuel
Accelerometer #1 - L.F. Cylinder Head
Vert.
2500 RPM 176 FT LBS Torque 25" HG
No Knock Detected

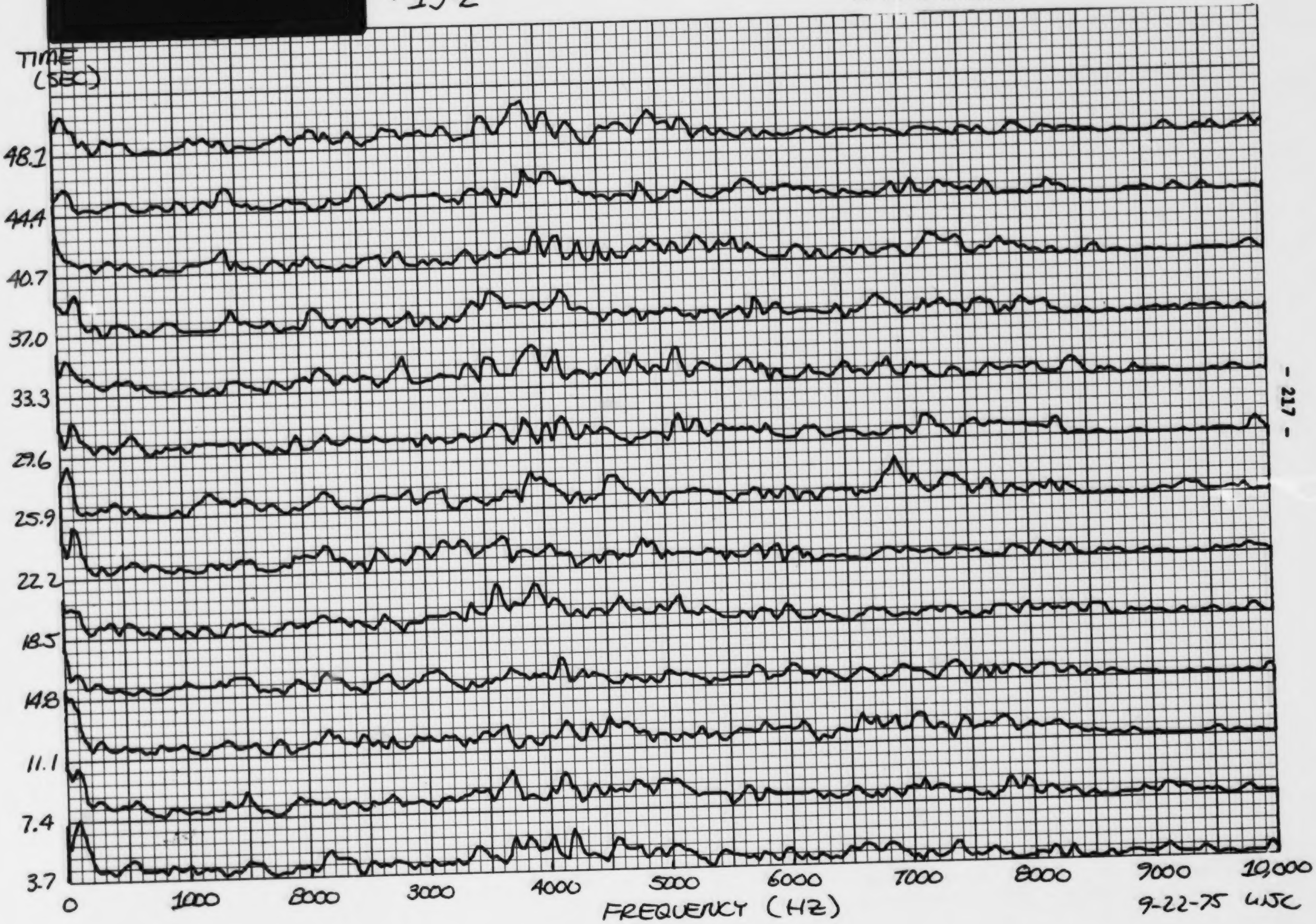


9-22-75 WJC

[redacted]

#13-2

Steady State Test - House Fuel
Accelerometer #2 - L.R. Cylinder Head
Vert.
2500 RPM 176 FT LBS Torque 25" HG
No Knock Detected

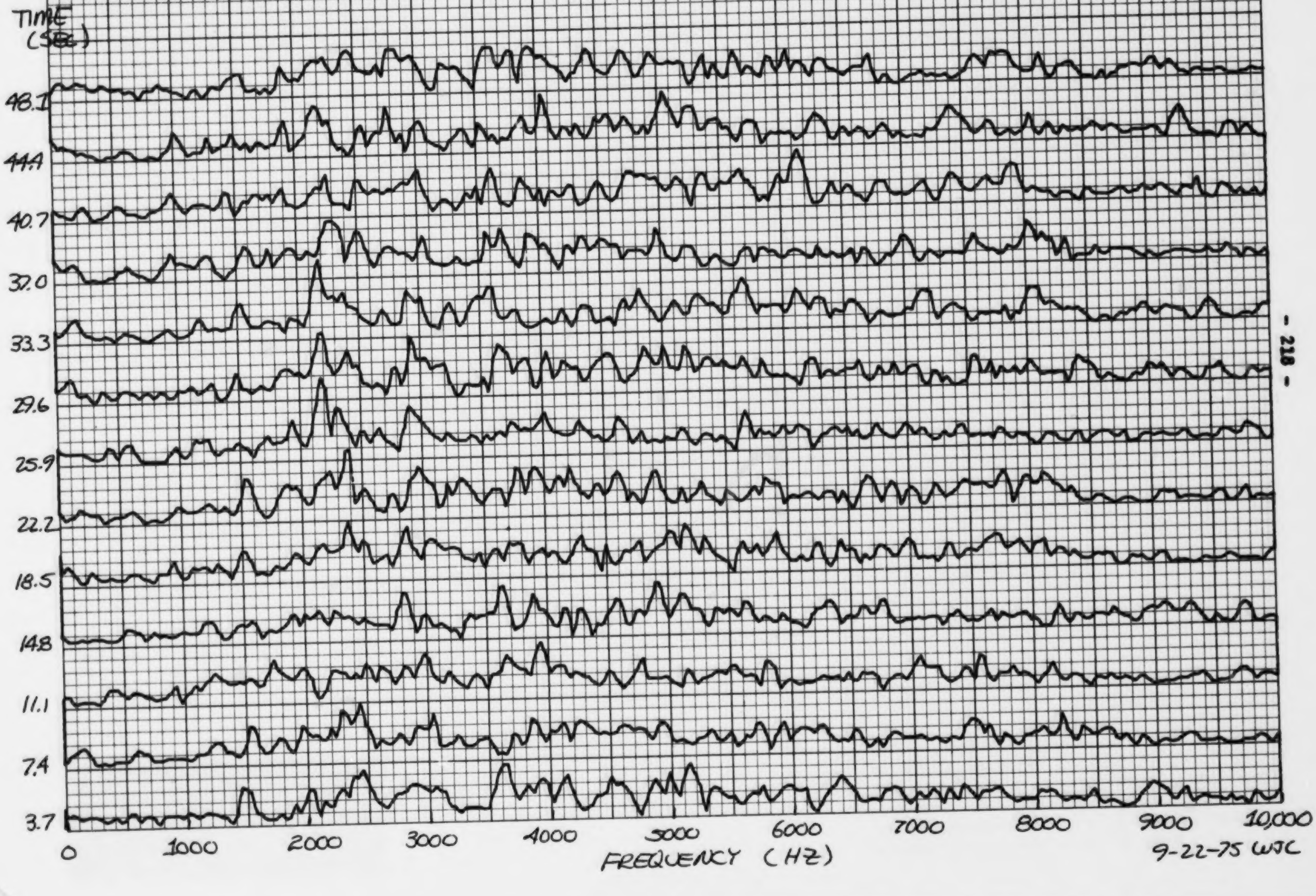


9-22-75 WJC

Seeady State Test - House Fuel
Accelerometer #3 - R. Intake Manifold
Vert.
2500 RPM 176 FT LBS Torqqe 25" HG
No Knock Detected

[redacted]

#13-3

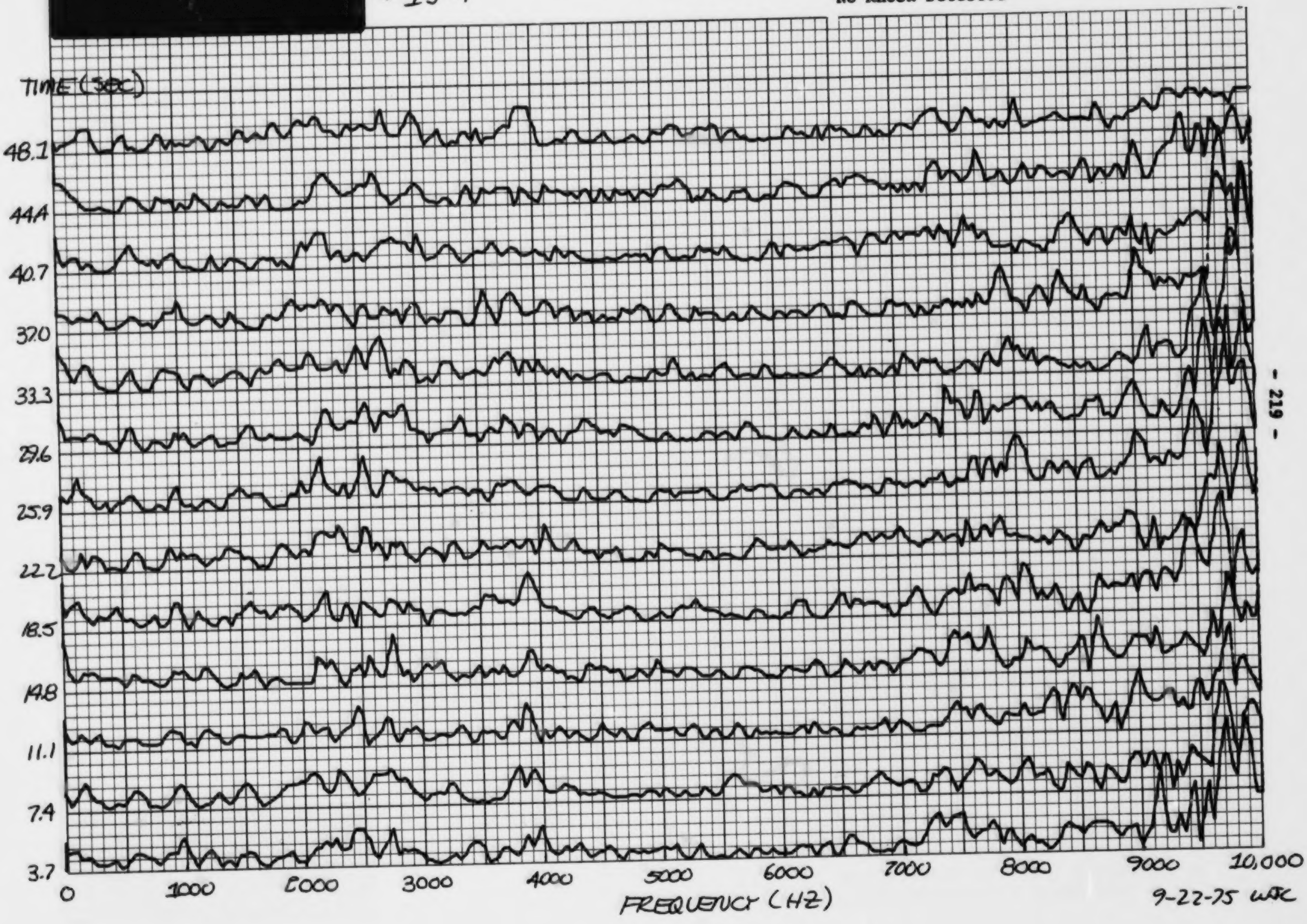


9-22-75 WJC

[redacted]

#13-4

Steady State Test - House Fuel
Accelerometer #4 - F. Intake Manifold
Vert.
2500 RPM 176 FT LBS Torque 25" HG
No Knock Detected

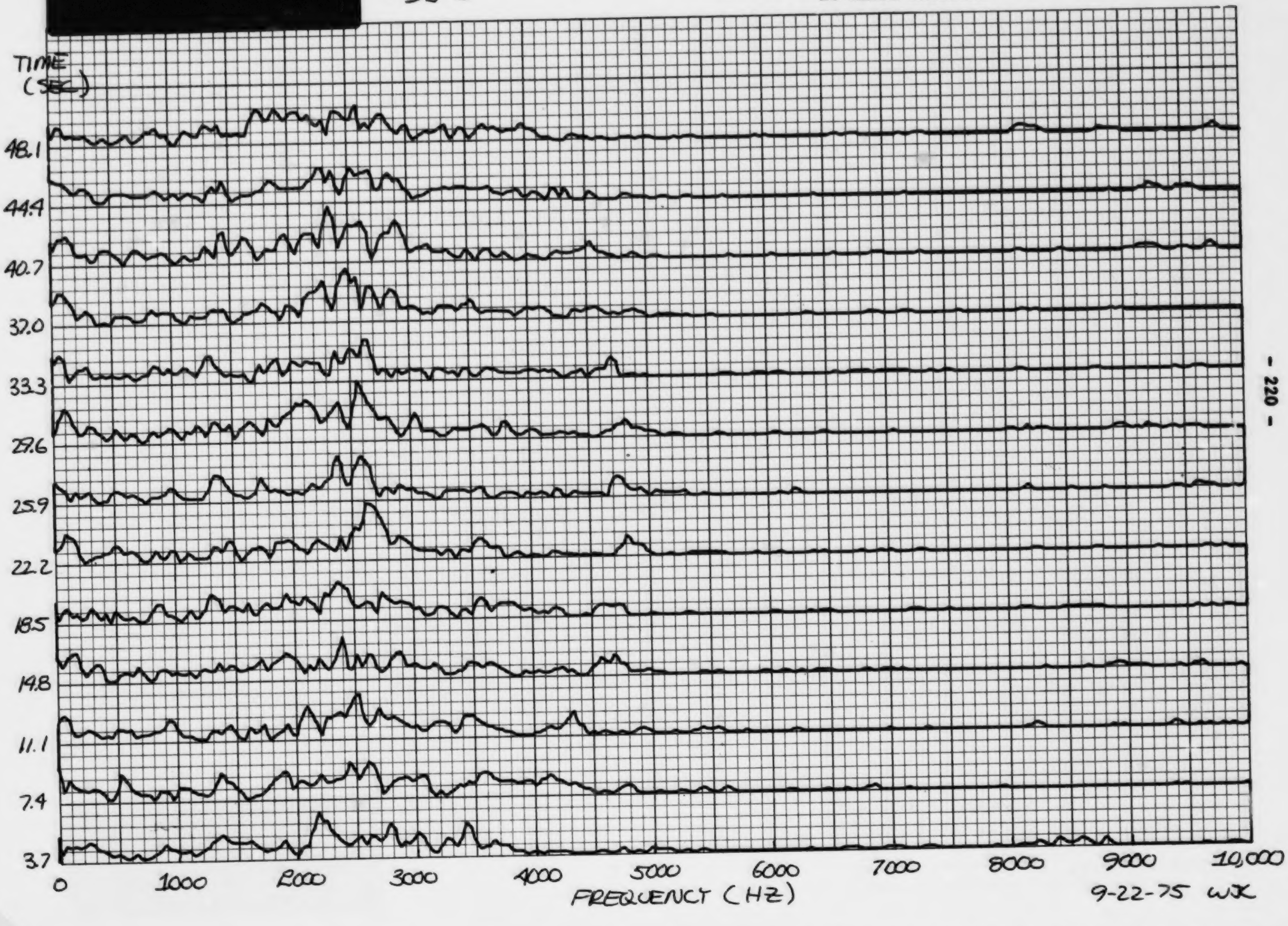


9-22-75 WRC

[redacted]

#13-5

Steady State Test - House Fuel
Accelerometer #5 - R.F. Cylinder Head
Vert.
2500 RPM 176 FT LBS Torque 25" HG
No Knock Detected

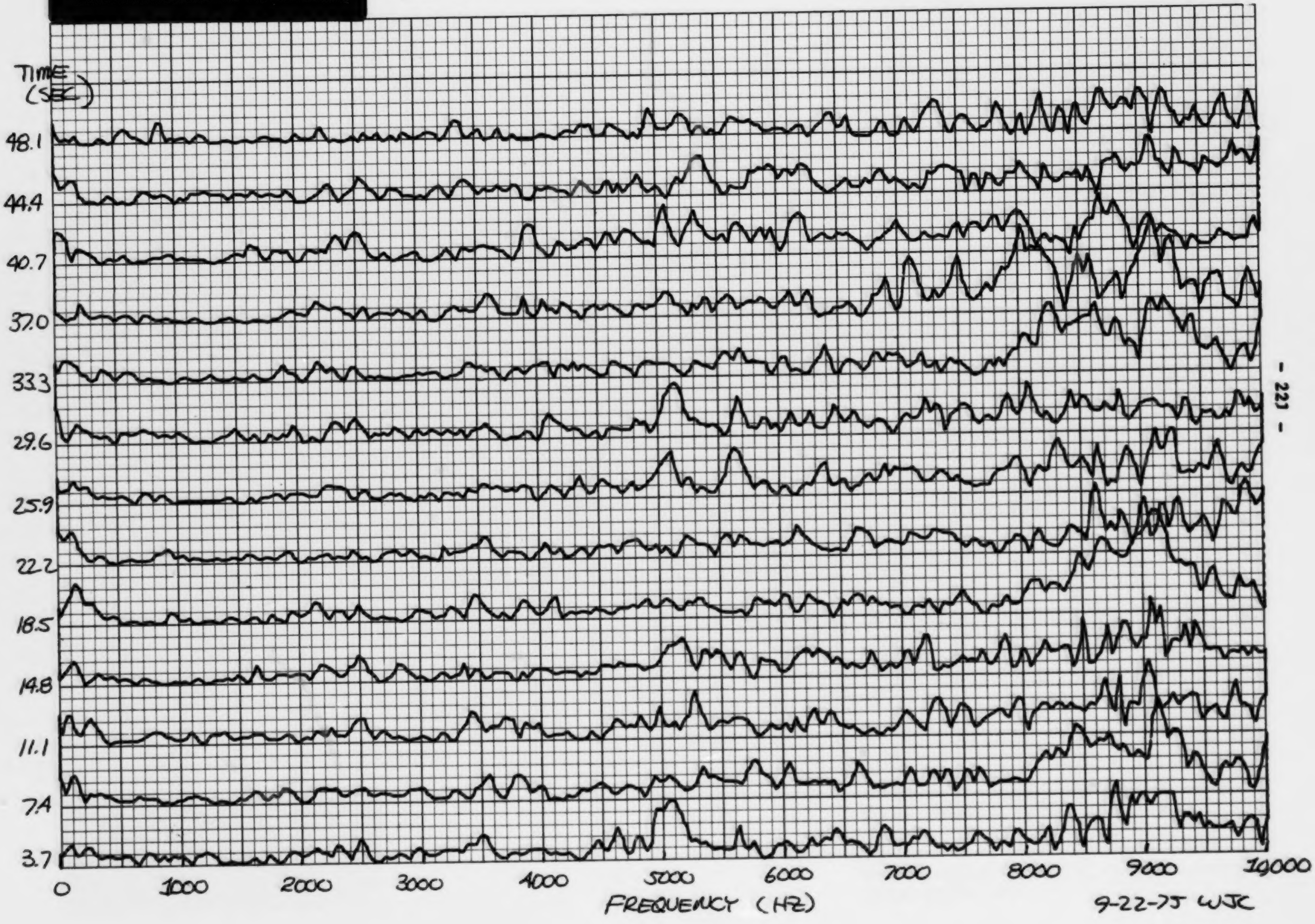


9-22-75 WK

[redacted]

#13-6

Steady State Test - House Fuel
Accelerometer #6 - R.R. Cylinder Head
  Hor.
2500 RPM 176 FT LBS Torque 25" HG
No Knock Detected

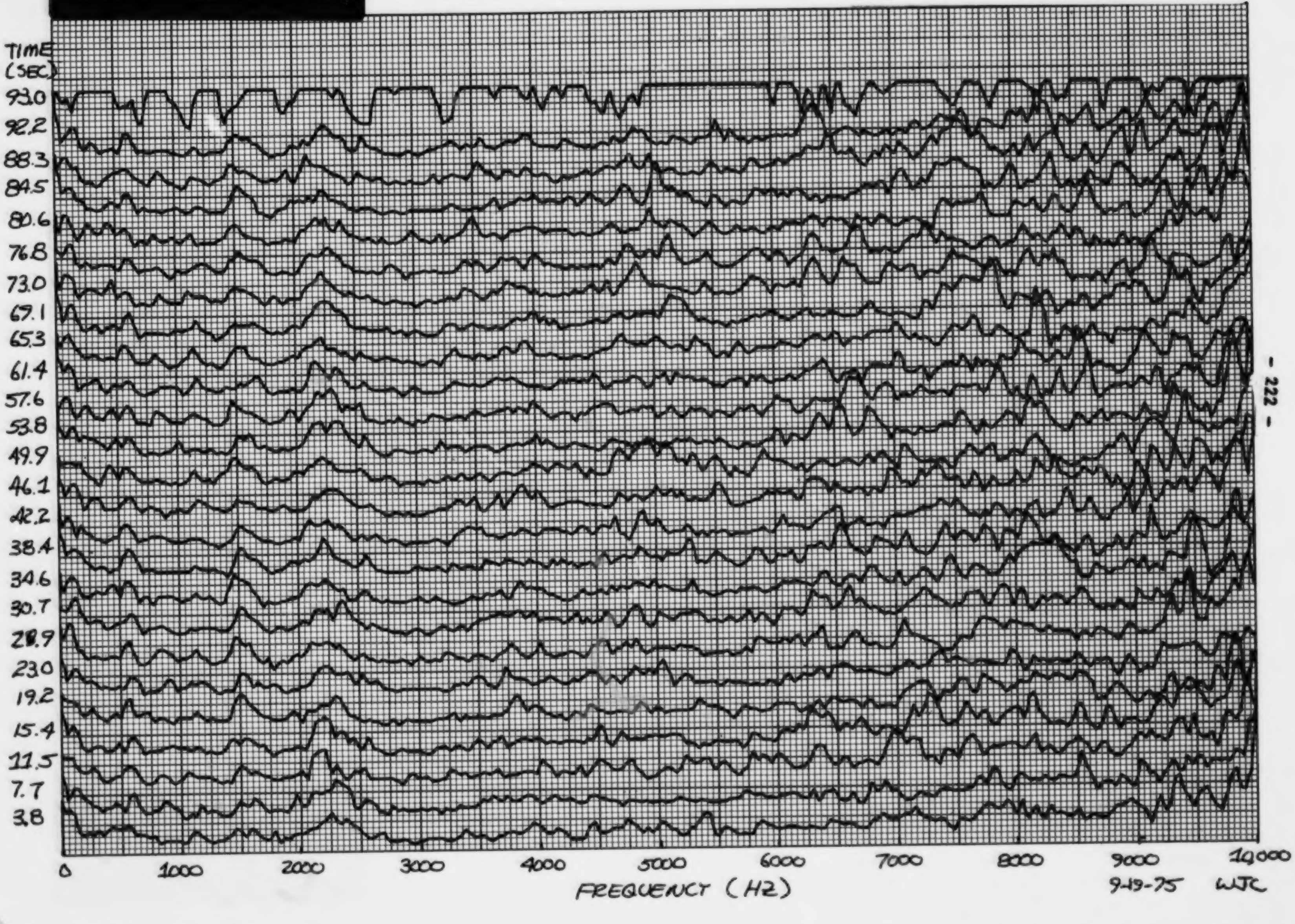


9-22-75 WJC

[redacted]

#14-1

Fuel Change Test
Accelerometer #1 - L.F. Cylinder Head
Vert.
2500 RPM 176 LBS Torque 25" HG
Knock Begins At Trace Level

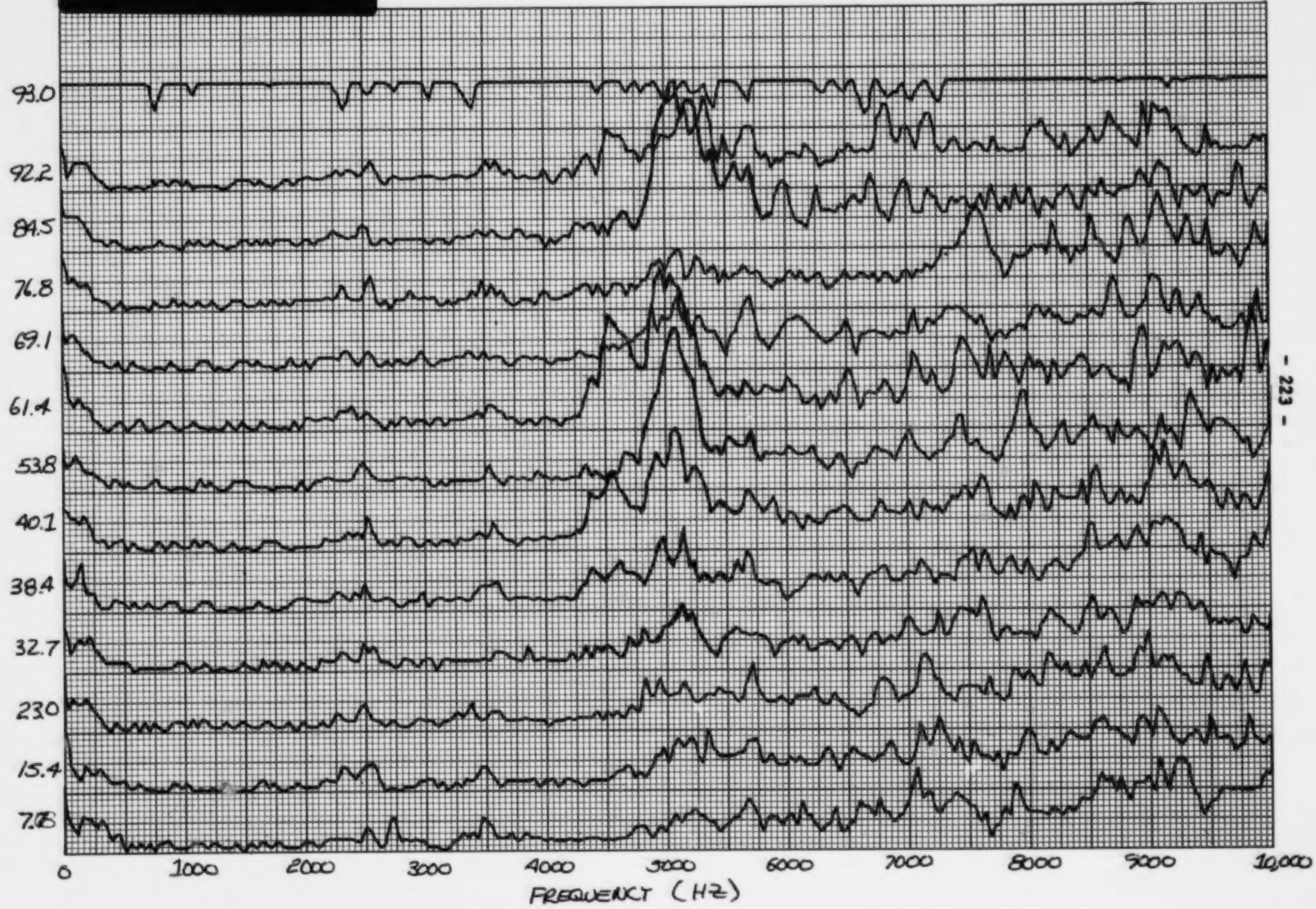


9-19-75 WJC

[redacted]

#14-6

Fuel Change Test
Accelerometer #6   R.R. Cylinder, Head
Hor.
2500 RPM 176 LBS Torque 25" HG
Knock Begins At Trace Level



TEST #2

350 CID Engine from Vehicle

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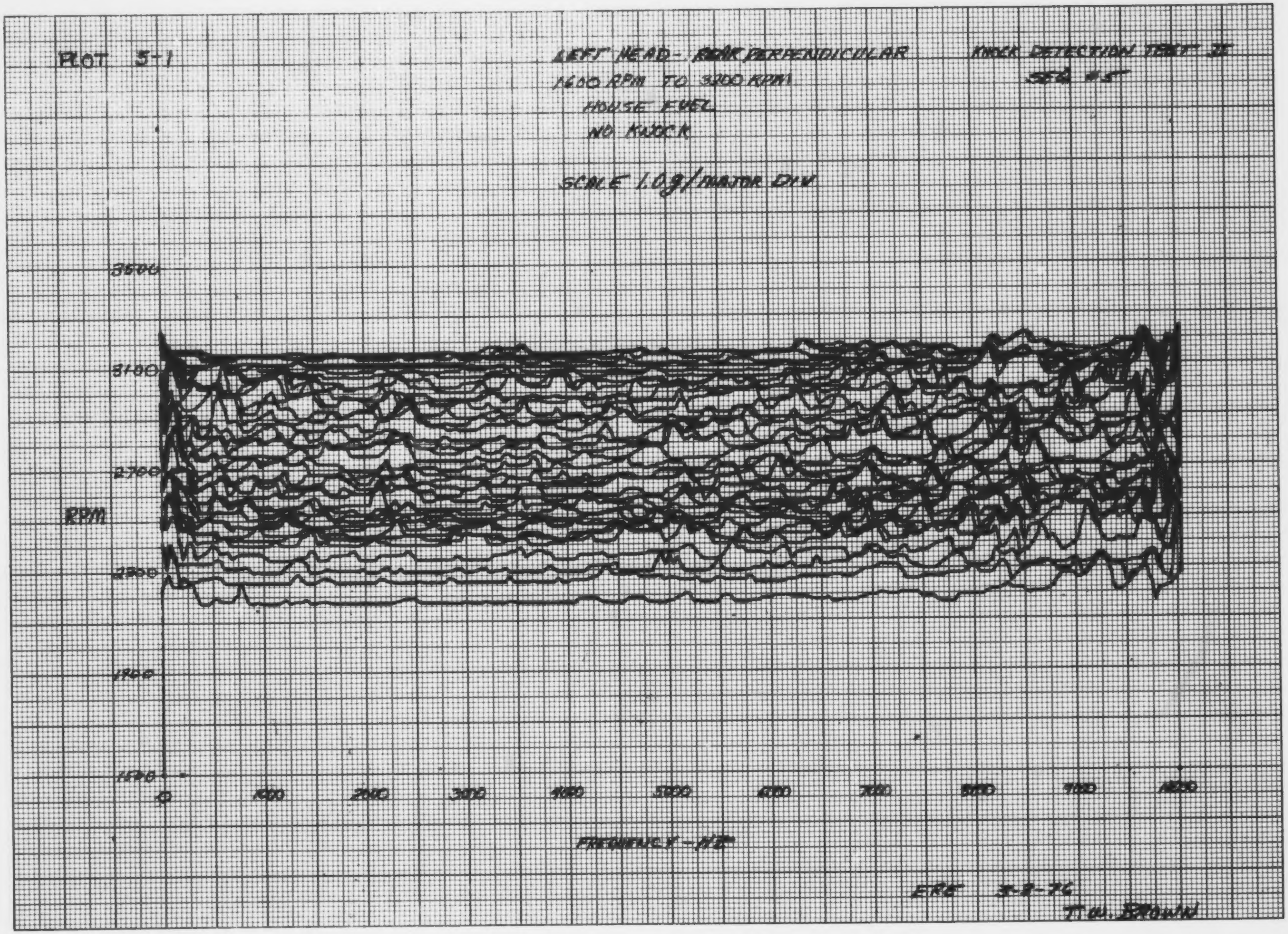
TEST #2

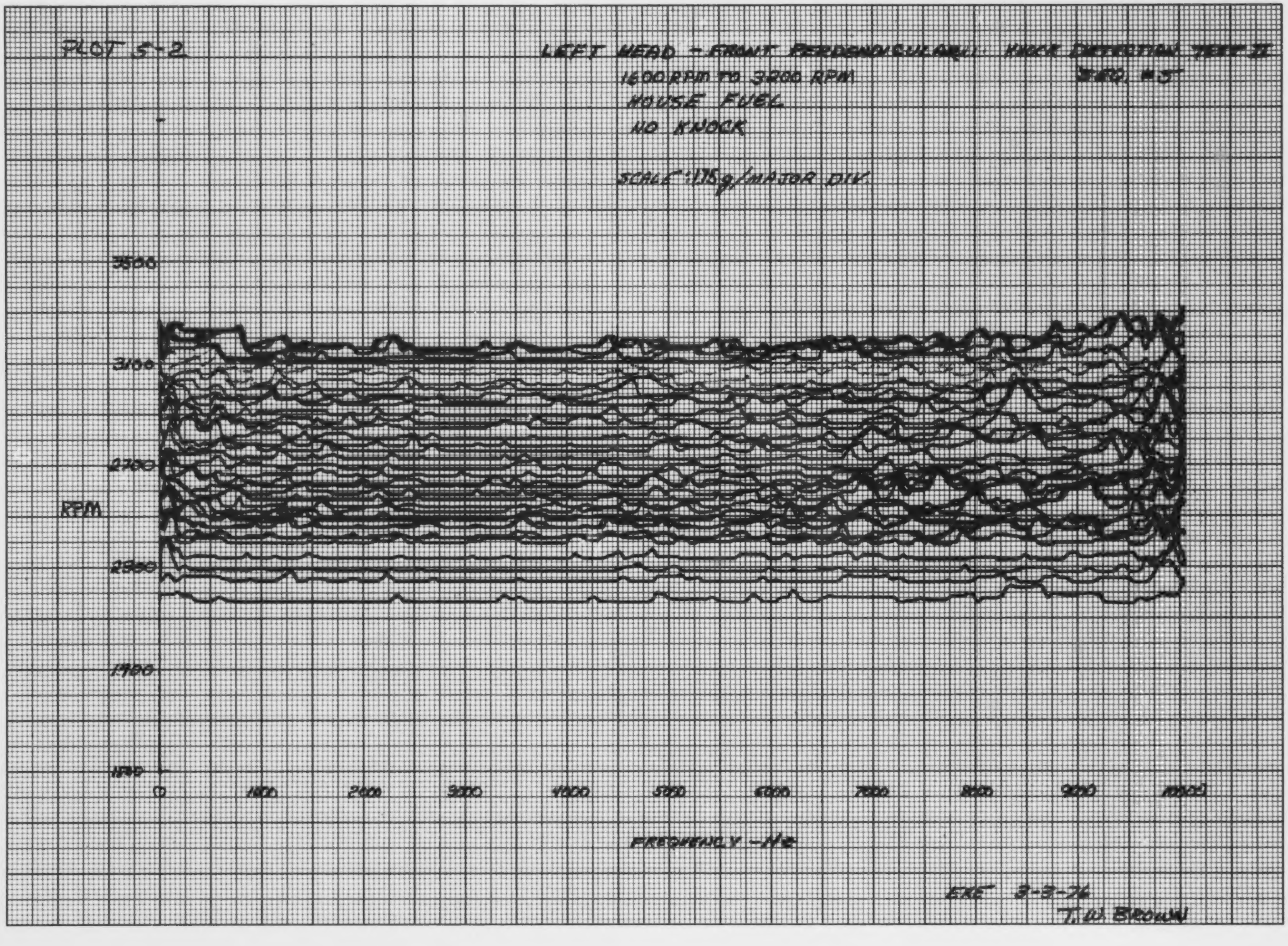
350 CID ENGINE FROM VEHICLE

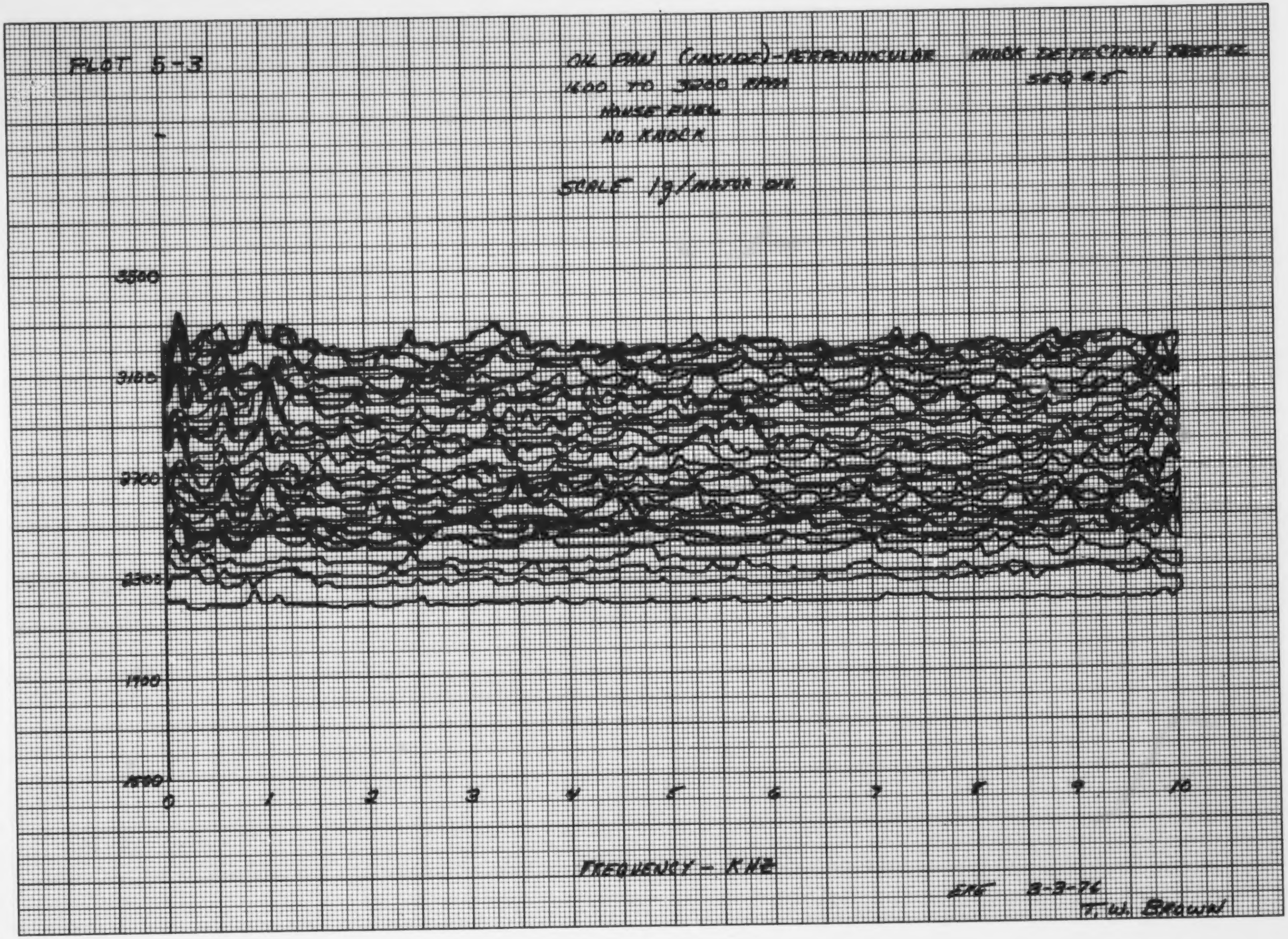
SUMMARY OF SPECTROGRAM RESULTS

Electronic Knock Detection Test 1975 CID Engine W/20,000 Miles

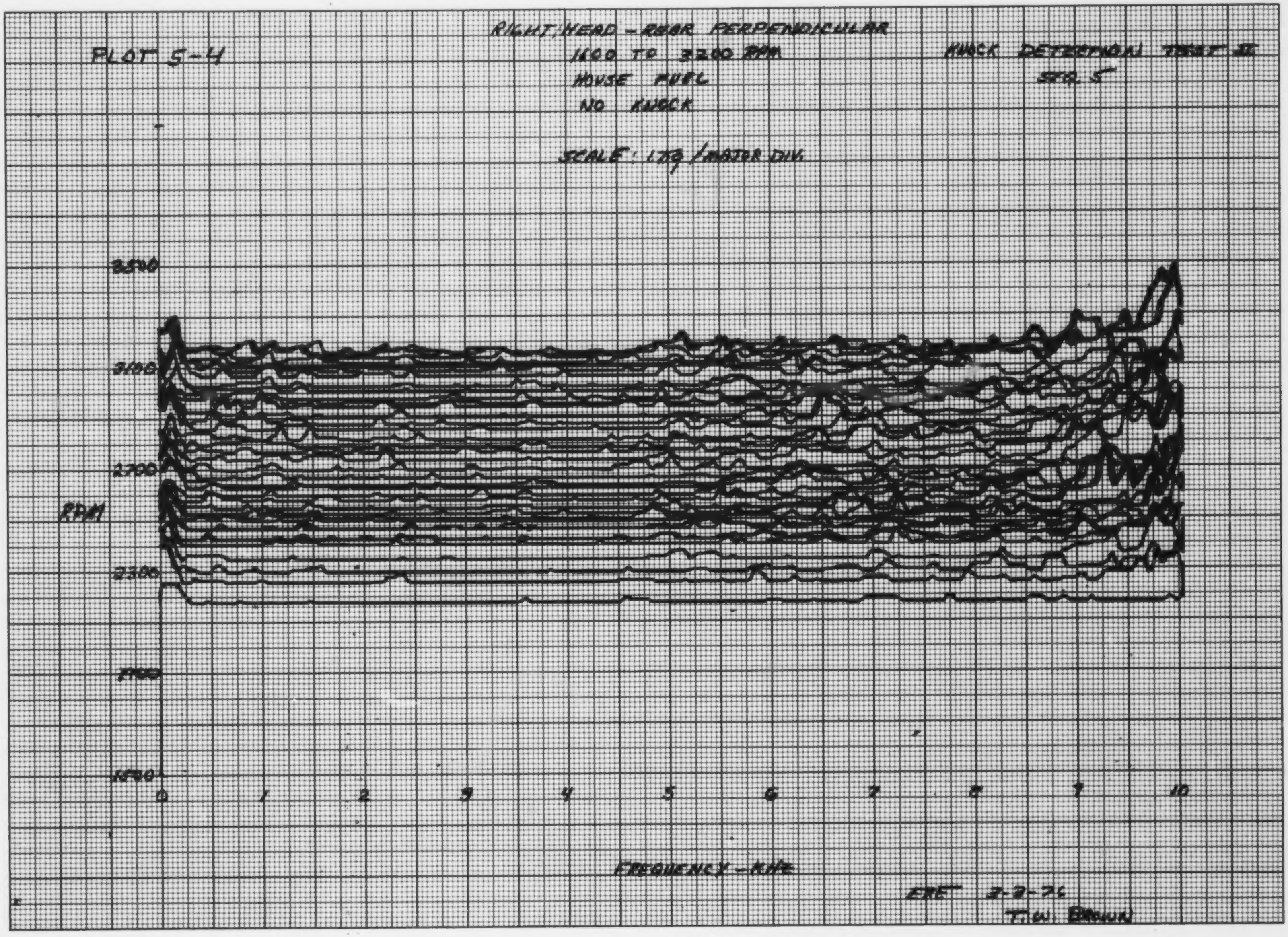
Plot No.	Accelerometer	Position Relative To Crank	Test	Plot Axis	Rated Knock Level	Maximum Response	Comments
5-1	Left Head-Rear	Perpendicular	Acceleration	RPM vs. Freq.	None		No Response
5-2	Left Head-Front	Perpendicular	Acceleration	RPM vs. Freq.	None		No Response
5-3	Oil Pan	Perpendicular	Acceleration	RPM vs. Freq.	None		No Response
5-4	Right Head-Rear	Perpendicular	Acceleration	RPM vs. Freq.	None		No Response
5-5	Right Head-Front	Perpendicular	Acceleration	RPM vs. Freq.	None		No Response
5-6	Right Head-Rear	Parallel	Acceleration	RPM vs. Freq.	None		No Response
8-1	Left Head-Rear	Perpendicular	Acceleration	RPM vs. Freq.	Very Light	0.9g	Medium Response
8-2	Left Head-Front	Perpendicular	Acceleration	RPM vs. Freq.	Very Light	0.8g	Medium Response
8-3	Oil Pan	Perpendicular	Acceleration	RPM vs. Freq.	Very Light	0.5g	Poor Response
8-4	Right Head-Rear	Perpendicular	Acceleration	RPM vs. Freq.	Very Light	1.6g	Good Response
8-5	Right Head-Front	Perpendicular	Acceleration	RPM vs. Freq.	Very Light	>5.0g	Repeated Plot 8-6
8-6	Right Head-Front	Perpendicular	Acceleration	RPM vs. Freq.	Very Light	8.0g	Good Response
8-7	Right Head-Rear	Parallel	Acceleration	RPM vs. Freq.	Very Light	3.1g	Good Response
11-1	Left Head-Rear	Perpendicular	Acceleration	RPM vs. Freq.	Trace Plus	0.7g	Poor Response
11-2	Left Head-Front	Perpendicular	Acceleration	RPM vs. Freq.	Trace Plus	0.7g	Poor Response
11-3	Oil Pan	Perpendicular	Acceleration	RPM vs. Freq.	Trace Plus	1.0g	Medium Response
11-4	Right Head-Rear	Perpendicular	Acceleration	RPM vs. Freq.	Trace Plus	1.0g	Medium Response
11-5	Right Head-Front	Perpendicular	Acceleration	RPM vs. Freq.	Trace Plus	2.2g	Good Response
11-6	Right Head-Rear	Parallel	Acceleration	RPM vs. Freq.	Trace Plus	4.0g	Good Response
14-1	Left Head-Rear	Perpendicular	Fuel Change	Time vs. Freq.	Trace Plus		No Response
14-2	Left Head-Front	Perpendicular	Fuel Change	Time vs. Freq.	Trace Plus		No Response
14-3	Oil Pan	Perpendicular	Fuel Change	Time vs. Freq.	Trace Plus	0.5g	Poor Response
14-4	Right Head-Rear	Perpendicular	Fuel Change	Time vs. Freq.	Trace Plus	1.0g	Medium Response
14-5	Right Head-Front	Perpendicular	Fuel Change	Time vs. Freq.	Trace Plus	1.6g	Good Response
14-6	Right Head-Rear	Parallel	Fuel Change	Time vs. Freq.	Trace Plus	0.6g	Medium Response
19-1	Left Head-Rear	Perpendicular	Acceleration	RPM vs. Freq.	Very Light Plus	1.7g	Good Response
19-2	Left Head-Rear	Parallel	Acceleration	RPM vs. Freq.	Very Light Plus	3.3g	Good Response
19-3	Oil Pan	Perpendicular	Acceleration	RPM vs. Freq.	Very Light Plus		No Response
19-4	Right Head-Rear	Perpendicular	Acceleration	RPM vs. Freq.	Very Light Plus	4.3g	Good Response
19-5	Right Head-Front	Perpendicular	Acceleration	RPM vs. Freq.	Very Light Plus	4.2g	Good Response
19-6	Right Head-Rear	Parallel	Acceleration	RPM vs. Freq.	Very Light Plus	3.6g	Good Response
22-1	Left Head-Rear	Perpendicular	Acceleration	RPM vs. Freq.	None		No Response
22-2	Left Head-Rear	Parallel	Acceleration	RPM vs. Freq.	None		Small Response Noted
22-3	Oil Pan	Perpendicular	Acceleration	RPM vs. Freq.	None		No Response
22-4	Right Head-Rear	Perpendicular	Acceleration	RPM vs. Freq.	None		No Response
22-5	Right Head-Front	Perpendicular	Acceleration	RPM vs. Freq.	None		No Response
22-6	Right Head Rear	Parallel	Acceleration	RPM vs. Freq.	None		Small Response Noted

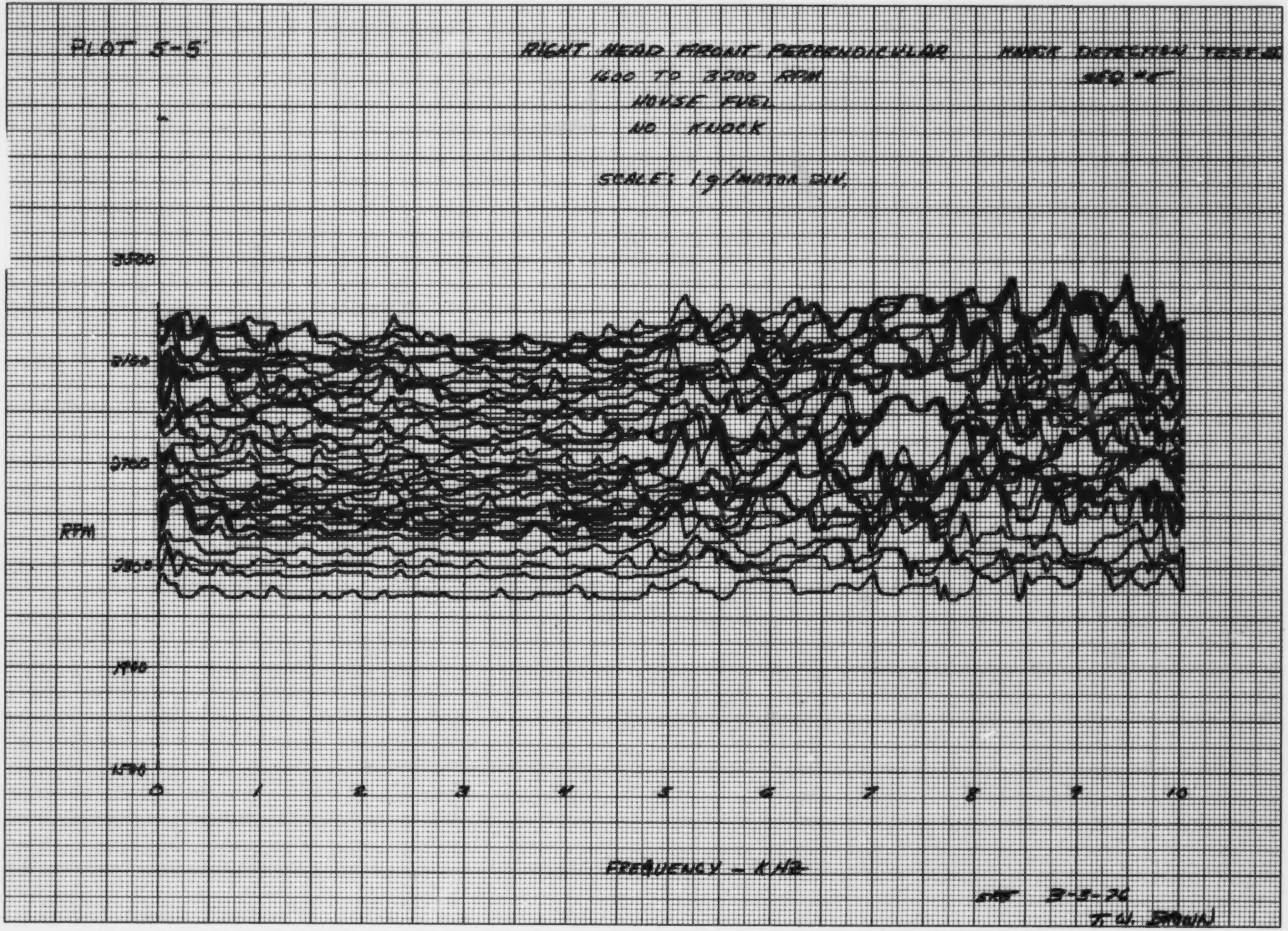

PLOT 5-1
LEFT HEAD- REAR PERPENDICULAR
1600 RPM TO 3200 RPM
HOUSE FUEL
NO KNOCK
SCALE 1.0g/MAJOR DIV
KNOCK DETECTION TEST II
SEQ #5
3500
3100
2700
RPM
2300
1900
1500
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
FREQUENCY - HZ
ERC 3-2-76
T.W. BROWN


PLOT 5-2
LEFT HEAD - FRONT PERPENDICULAR(L) KNOCK DETECTION TEST II
SEQ. #5
1600 RPM TO 3200 RPM
HOUSE FUEL
NO KNOCK
SCALE 1.75g/MAJOR DIV.
RPM
3500
3100
2700
2300
1900
1500
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
FREQUENCY - HZ
EXE 3-3-76
T.W. BROWN


PLOT 5-3

OIL PAN (INSIDE)-PERPENDICULAR KNOCK DETECTION TEST II
SEQ #5
1600 TO 3200 RPM
HOUSE FUEL
NO KNOCK
SCALE 1g/MAJOR DIV.
3500
3100
2700
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHZ
EAE 3-3-76
T. W. BROWN


PLOT 5-4
RIGHT HEAD - REAR PERPENDICULAR
1600 TO 3200 RPM
HOUSE FUEL
NO KNOCK
SCALE: 1 G / MAJOR DIV.
KNOCK DETECTION TEST II
SEQ. 5
3500
3100
2700
2300
1900
1500
RPM
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHz
ERE 2-2-76
T.W. BROWN

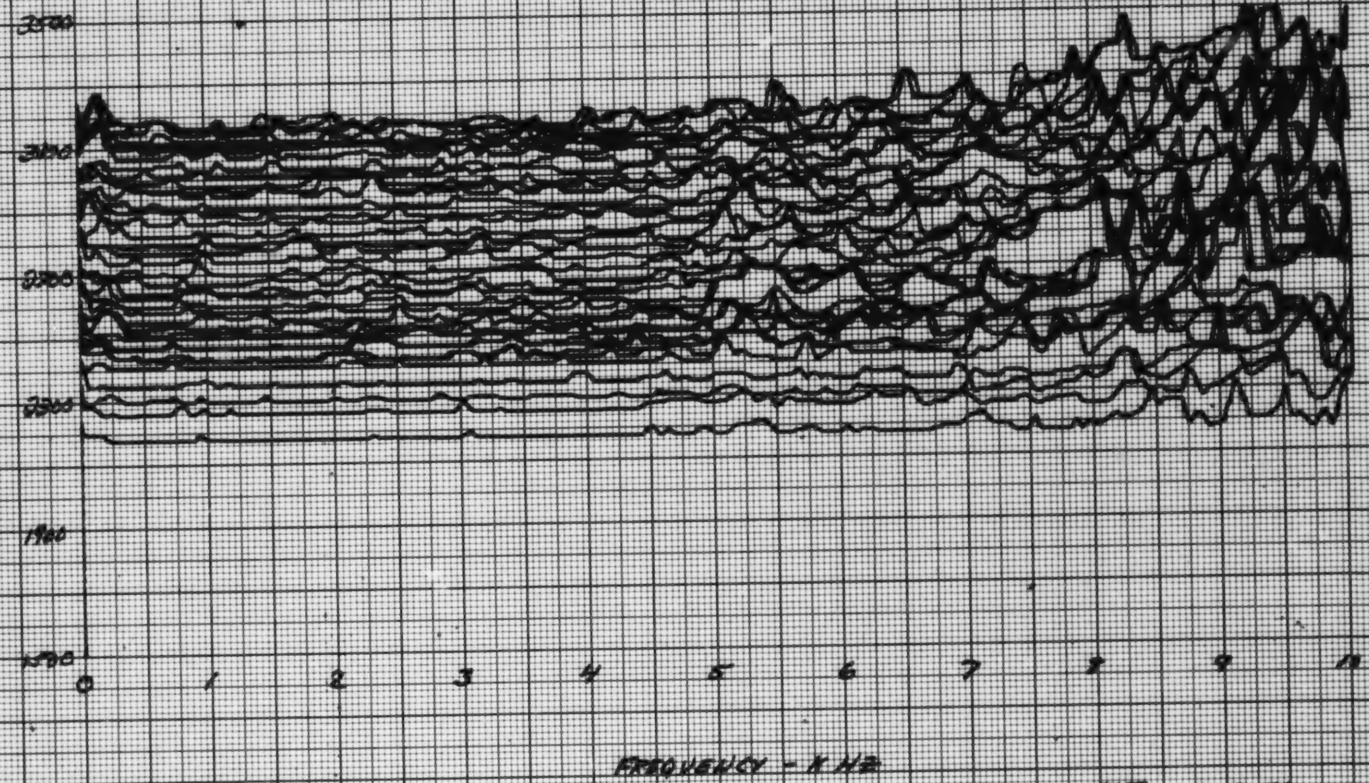

PLOT 5-5
RIGHT HEAD FRONT PERPENDICULAR
KNOCK DETECTION TEST
SEQ #5
1600 TO 3200 RPM
HOUSE FUEL
NO KNOCK
SCALE: 1 g/MOTOR DIV.
3500
3100
2700
2300
1900
1500
RPM
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY – KHZ
3-3-76
J. W. BROWN

PLOT 5-6

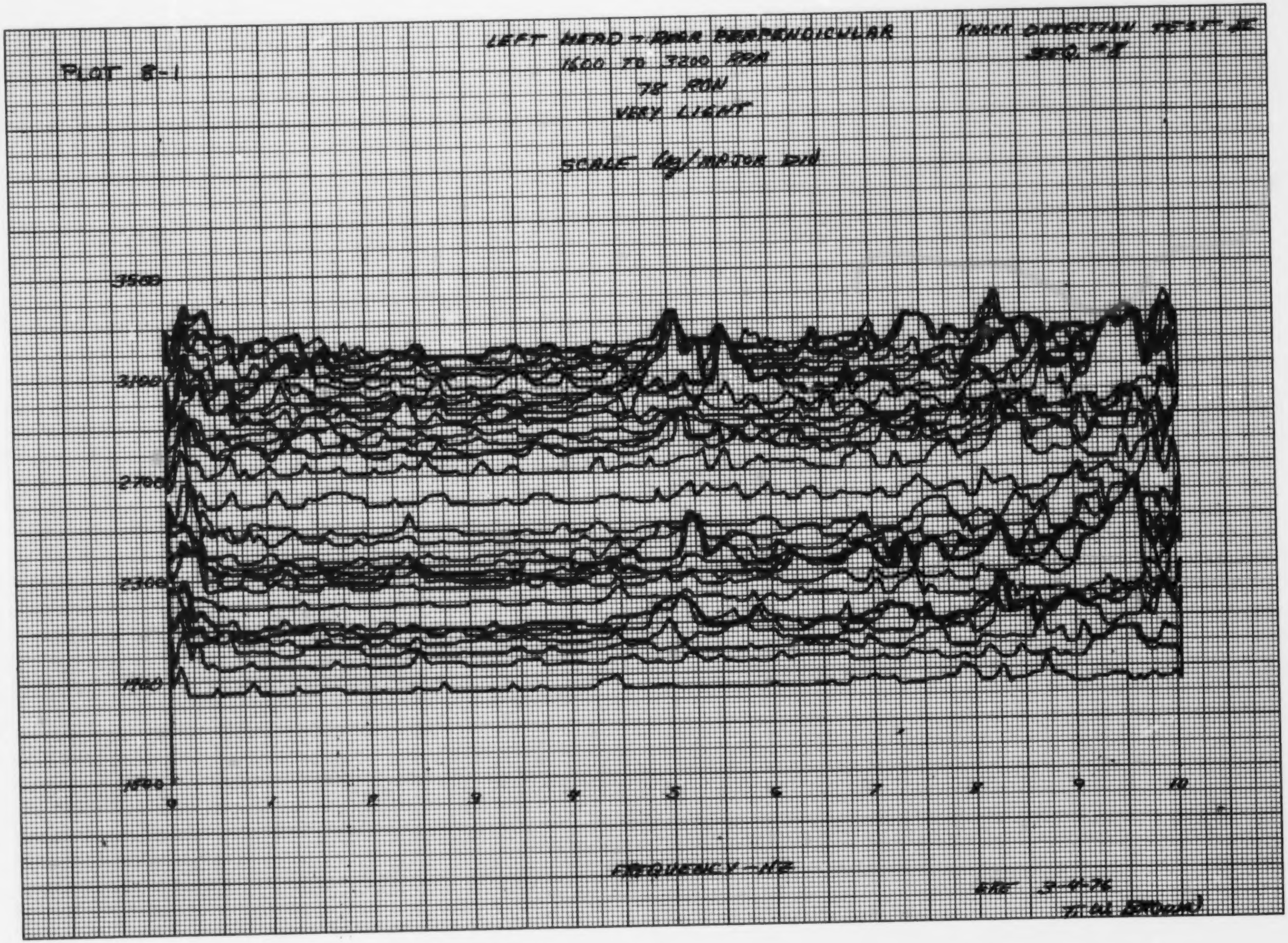
RIGHT HEAD – REAR PARALLEL
1600 TO 3200 RPM
NUKE FUEL
NO KNOCK

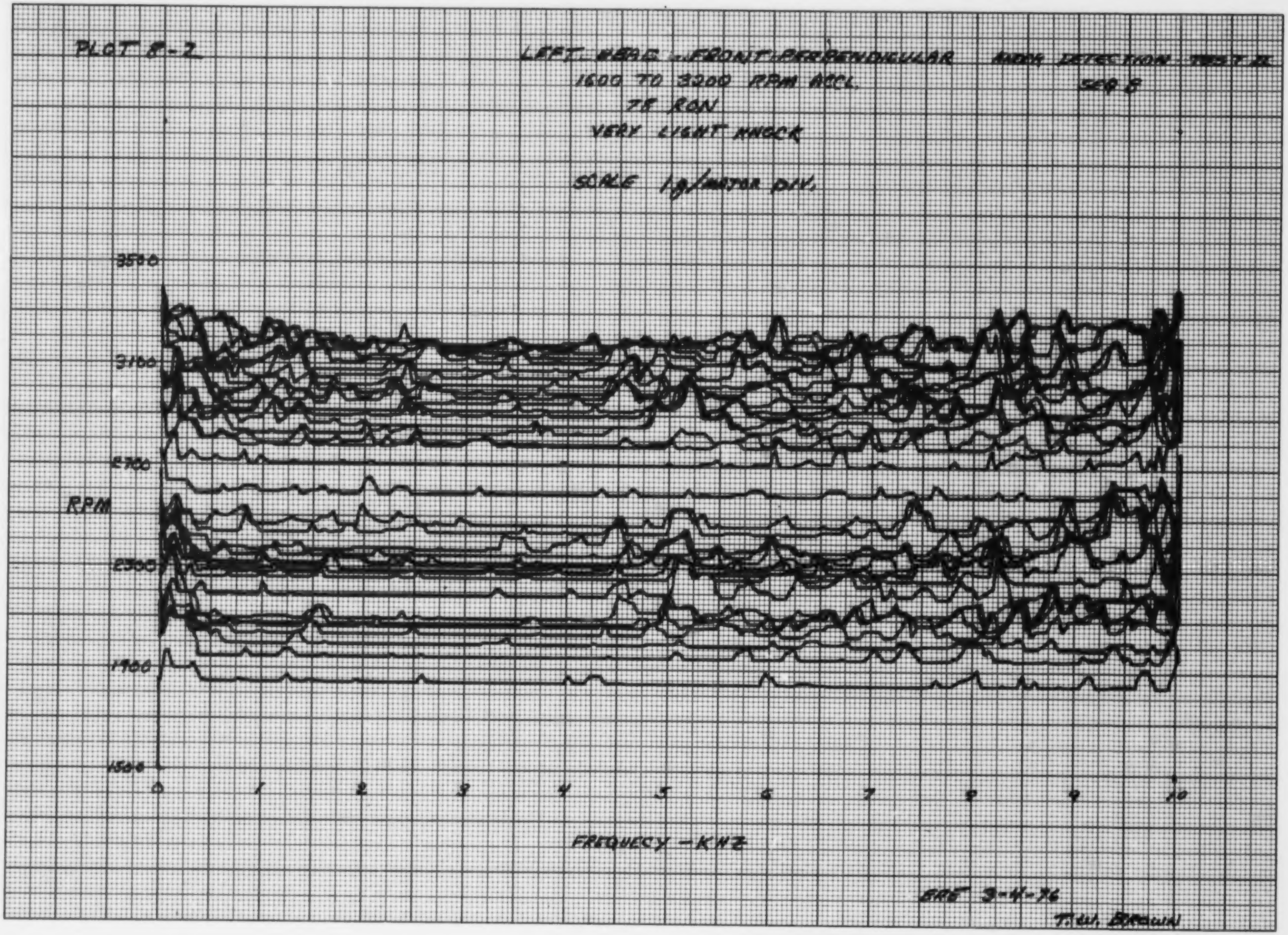
SCALE 1.25 g/MAJOR DIV.

KNOCK DETECTION TEST II
520 #5



AMF 3-3-74
T.W. Brown


PLOT 8-1
LEFT HEAD – REAR PERPENDICULAR
1600 TO 3200 RPM
78 RON
VERY LIGHT
SCALE 1g/MAJOR DIV
KNOCK DETECTION TEST II
SEQ. #I
3500
3100
2700
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY – HZ
EKG 3-4-76

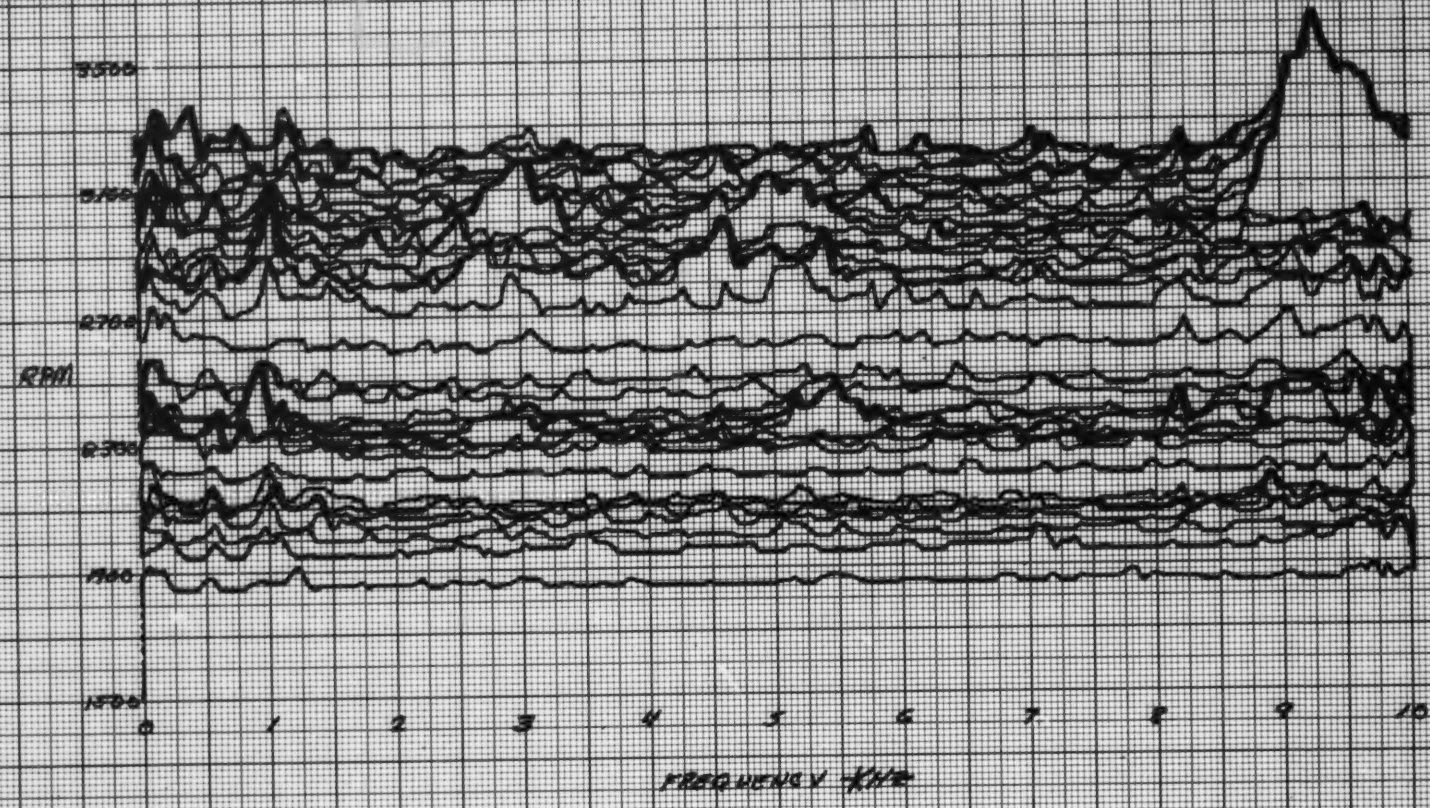

PLOT 8-2
LEFT REAR - FRONT PERPENDICULAR
KNOCK DETECTION TEST II
SEQ 8
1600 TO 3200 RPM ACCL.
78 RON
VERY LIGHT KNOCK
SCALE 1g/MAJOR DIV.
3500
3100
2700
RPM
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUECY - KHZ
SRE 3-4-76
T.W. BROWN

PLOT 8-3

OIL PAN (INSIDE) PERPENDICULAR KNOCK DETECTION TEST II
1600 TO 3200 RPM
78 RON
VERY LIGHT

560°F

SCALE 1.0 g/MAJOR DIV.



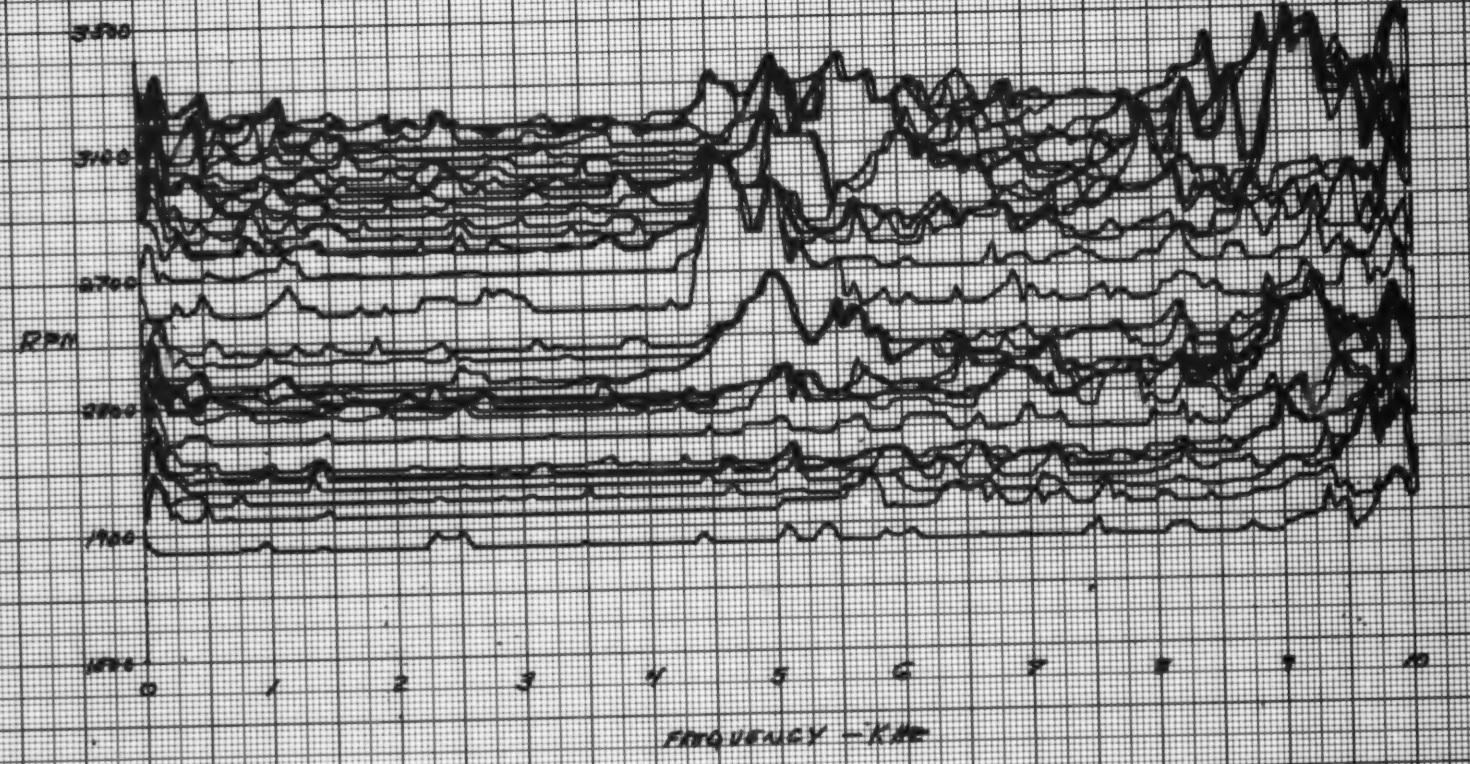
ERF 5-4-76
T.W. BROWN

PLOT 8-4

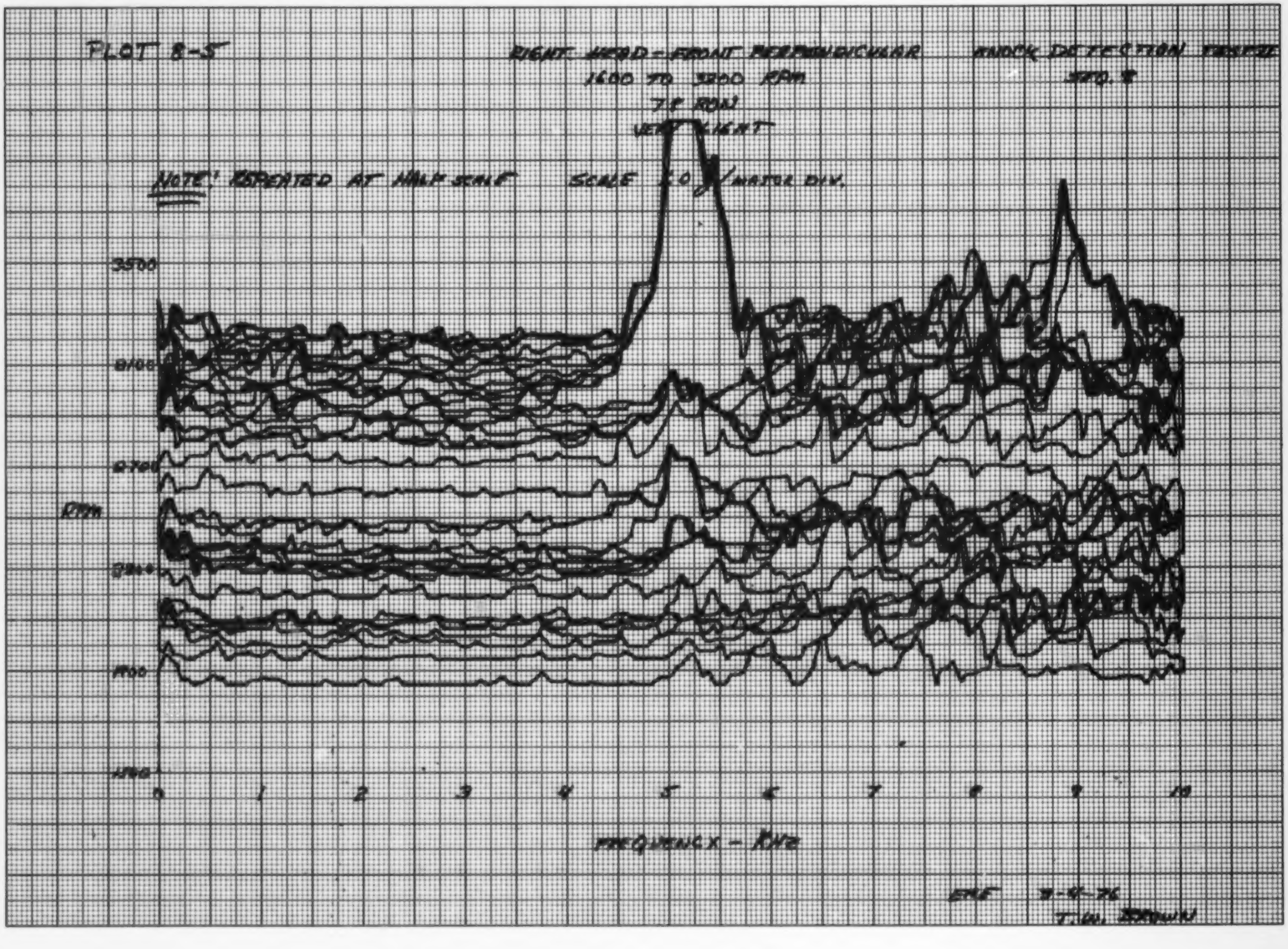
RIGHT HEAD - REAR PERPENDICULAR KNOCK DETECTION TEST II
1600 TO 3200 RPM
78 RON
VERY LIGHT

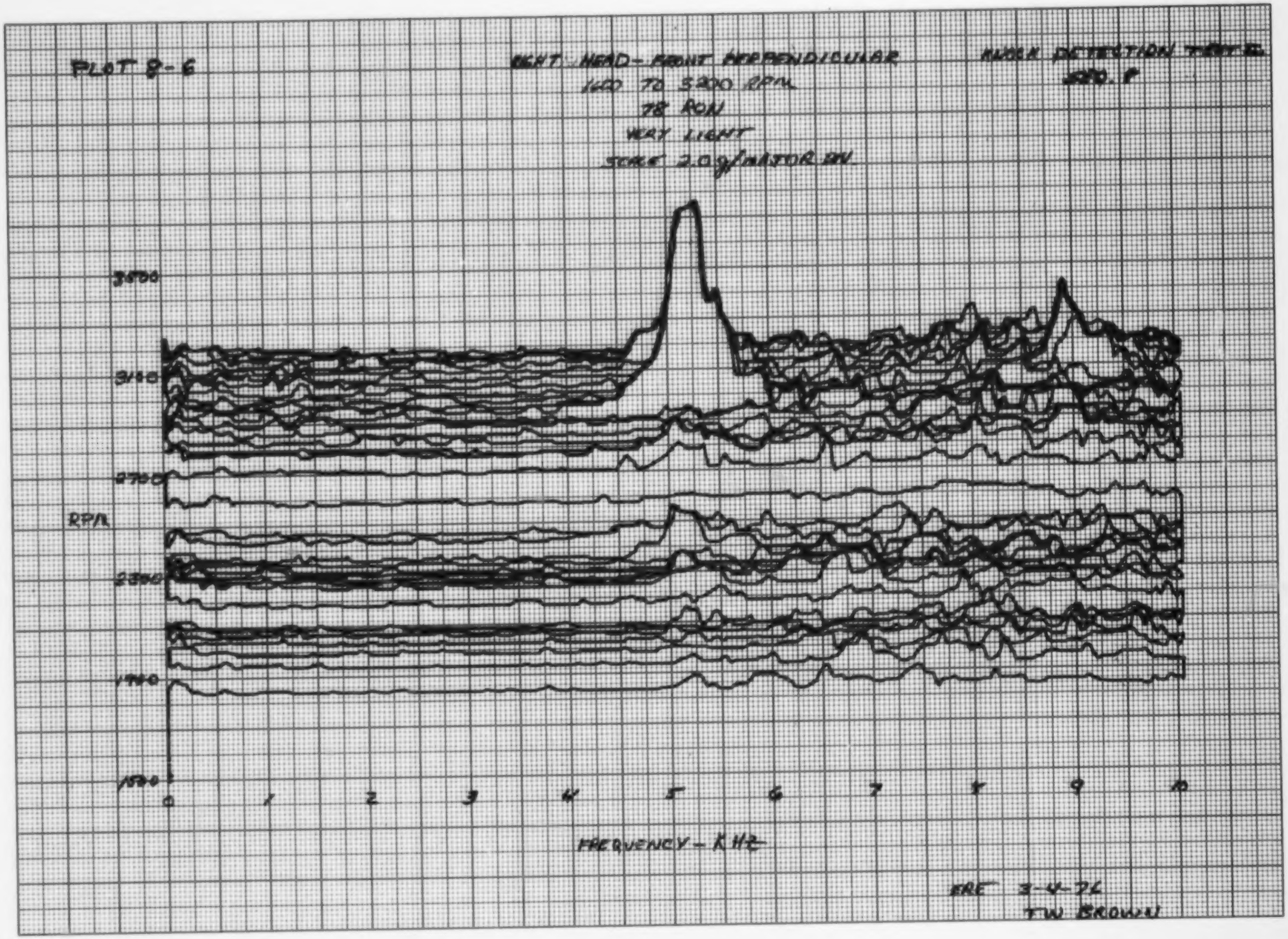
SEQ 8

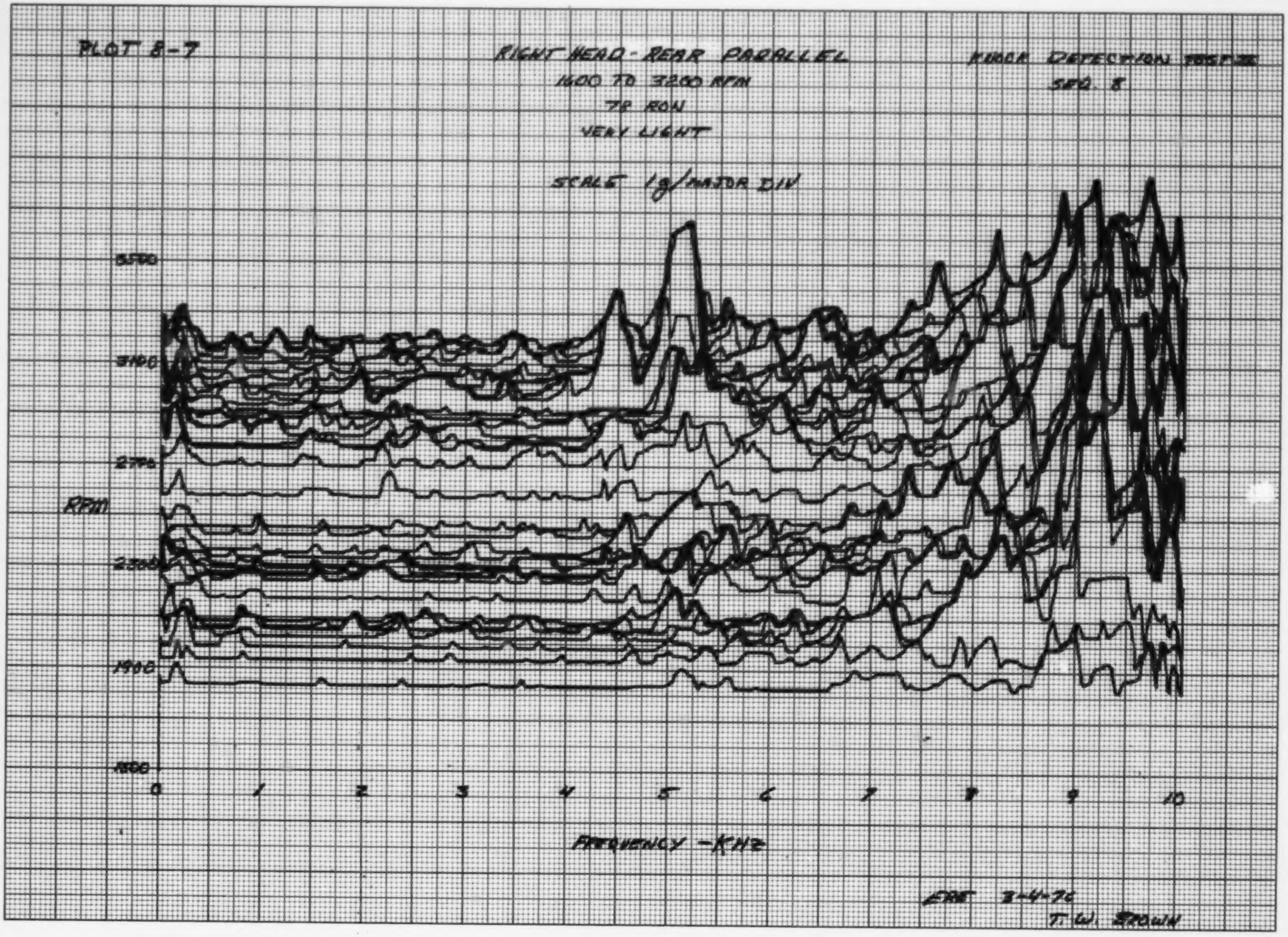
SCALE 1.0 g/MAJOR DIV.

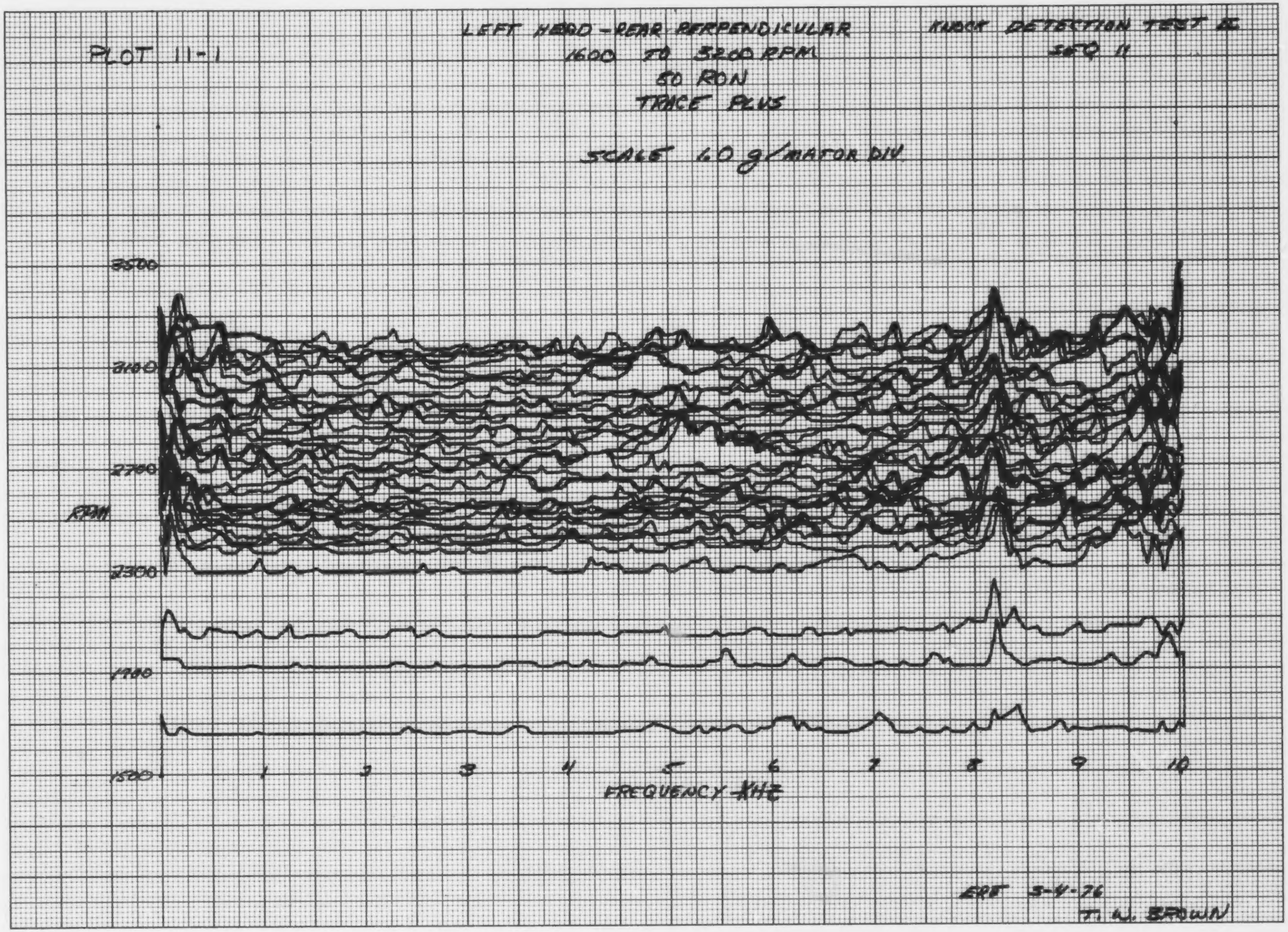


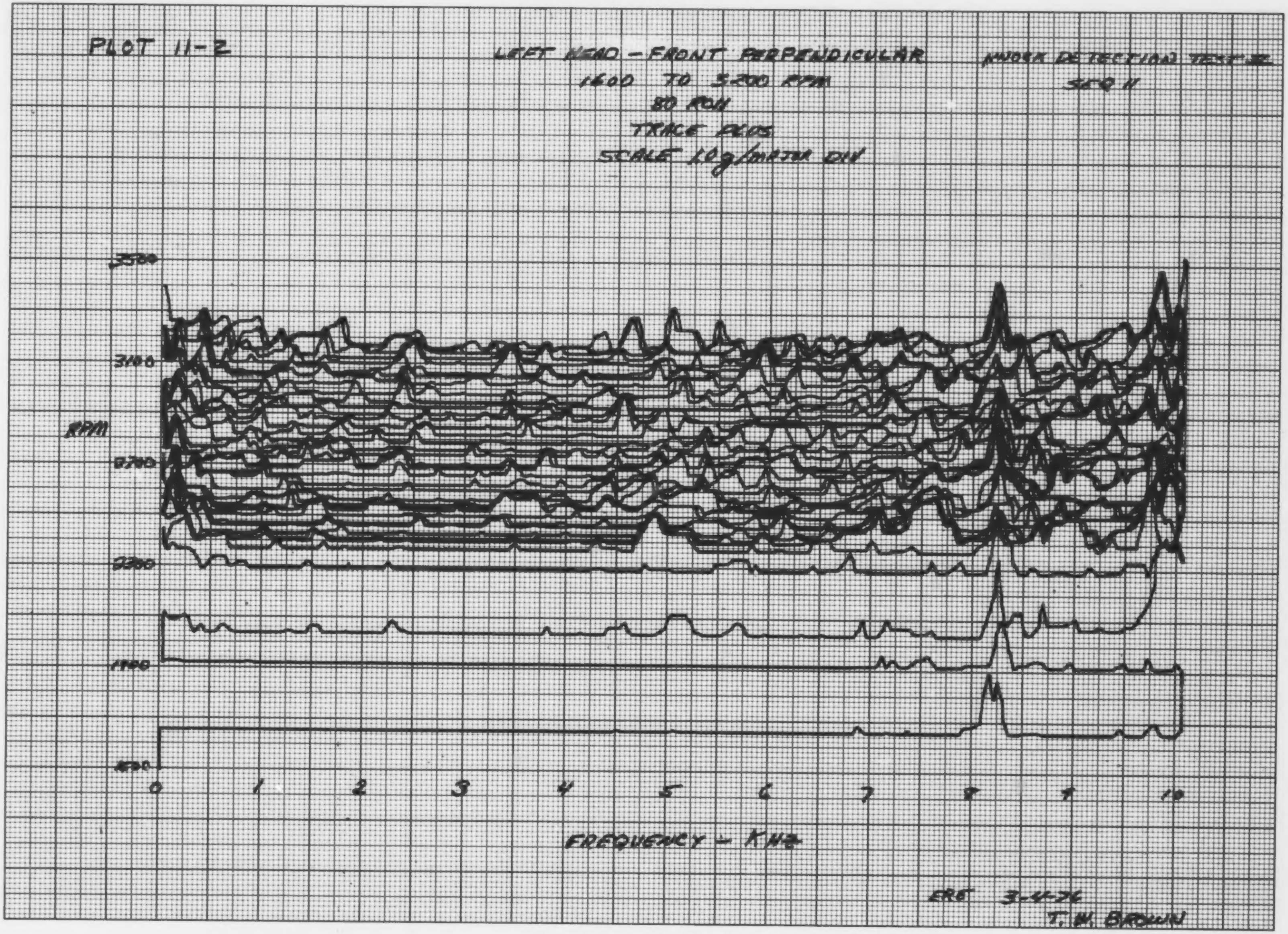
ENF 3-4-76
T.W. BROWN

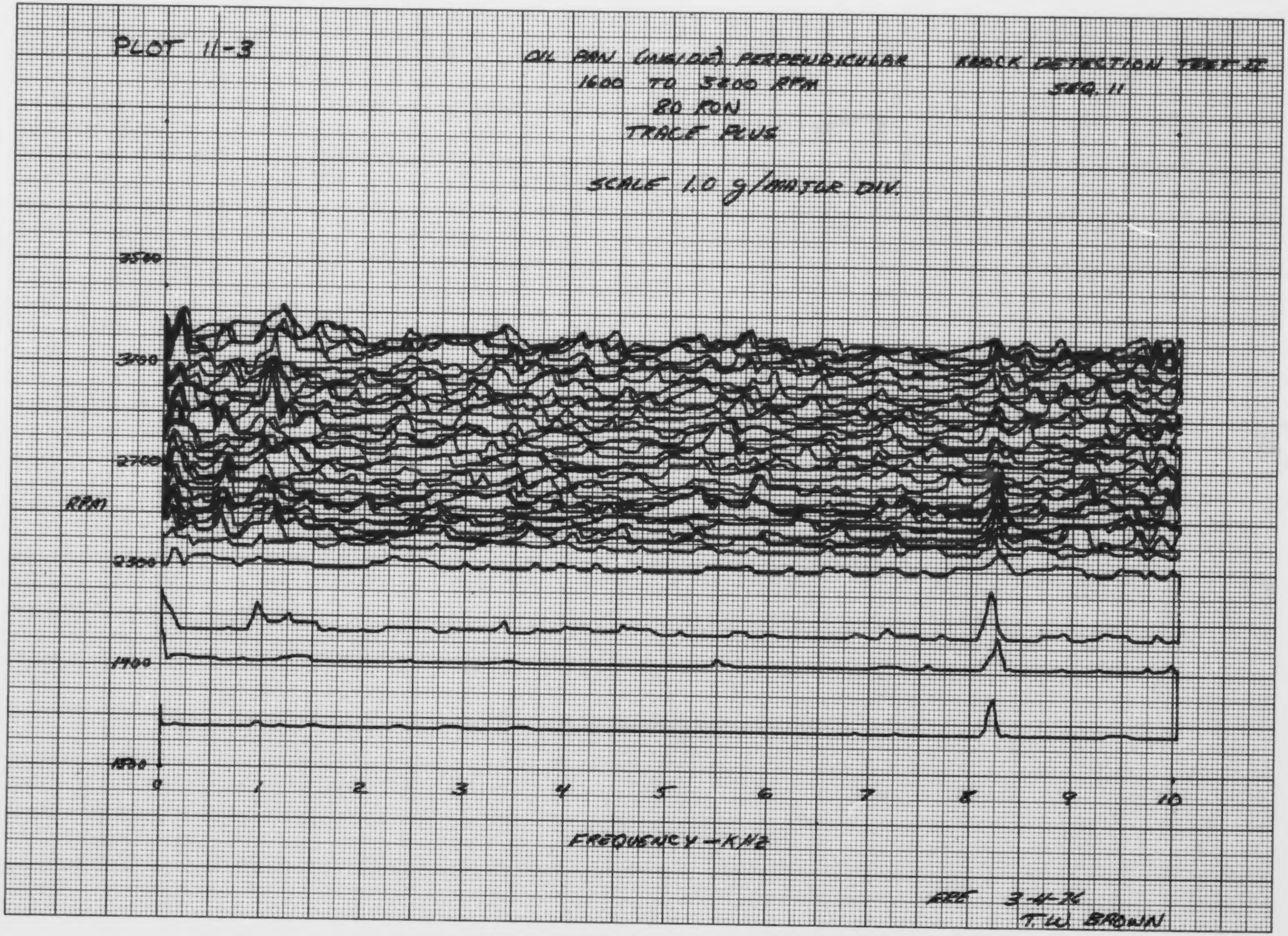

PLOT 8-5
RIGHT HEAD - FRONT PERPENDICULAR
KNOCK DETECTION TESTS
1600 TO 3200 RPM
STD. II
7/8 RON
VERY LIGHT
NOTE: REPEATED AT HALF SCALE
SCALE 1.0 g/MAJOR DIV.
3500
3100
2700
RPM
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHZ
EMF 9-9-76
T.W. BROWN


PLOT 8-6
RGHT. HEAD- FRONT PERPENDICULAR
1600 TO 3200 RPM
78 RON
VERY LIGHT
SCALE 2.0 g/MAJOR DIV
KNOCK DETECTION TEST II
220. F
RPM
3500
3100
2700
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHz
ERE 3-4-76
T.W. BROWN


PLOT 8-7
RIGHT HEAD - REAR PARALLEL
1600 TO 3200 RPM
72 RON
VERY LIGHT
SCALE 1g/MAJOR DIV
KNOCK DETECTION TEST II
SEQ. 8
RPM
3500
3100
2700
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHZ
ERE 3-4-76
T. W. BROWN


PLOT 11-1
LEFT HEAD - REAR PERPENDICULAR
1600 TO 3200 RPM
80 RON
TRACE PLUS
KNOCK DETECTION TEST II
SEQ 11
SCALE 1.0 g/MAJOR DIV
3500
3100
2700
RPM
2300
1900
1500
1
2
3
4
5
6
7
8
9
10
FREQUENCY KHZ
ERF 3-4-76
T. W. BROWN


PLOT 11-2
LEFT HEAD - FRONT PERPENDICULAR
1600 TO 3200 RPM
80 RON
TRACE ADDS
SCALE 10g/MAJOR DIV
KNOCK DETECTION TEST II
SEQ 11
RPM
3500
3100
2700
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHz
ERE 3-4-76
T. W. BROWN



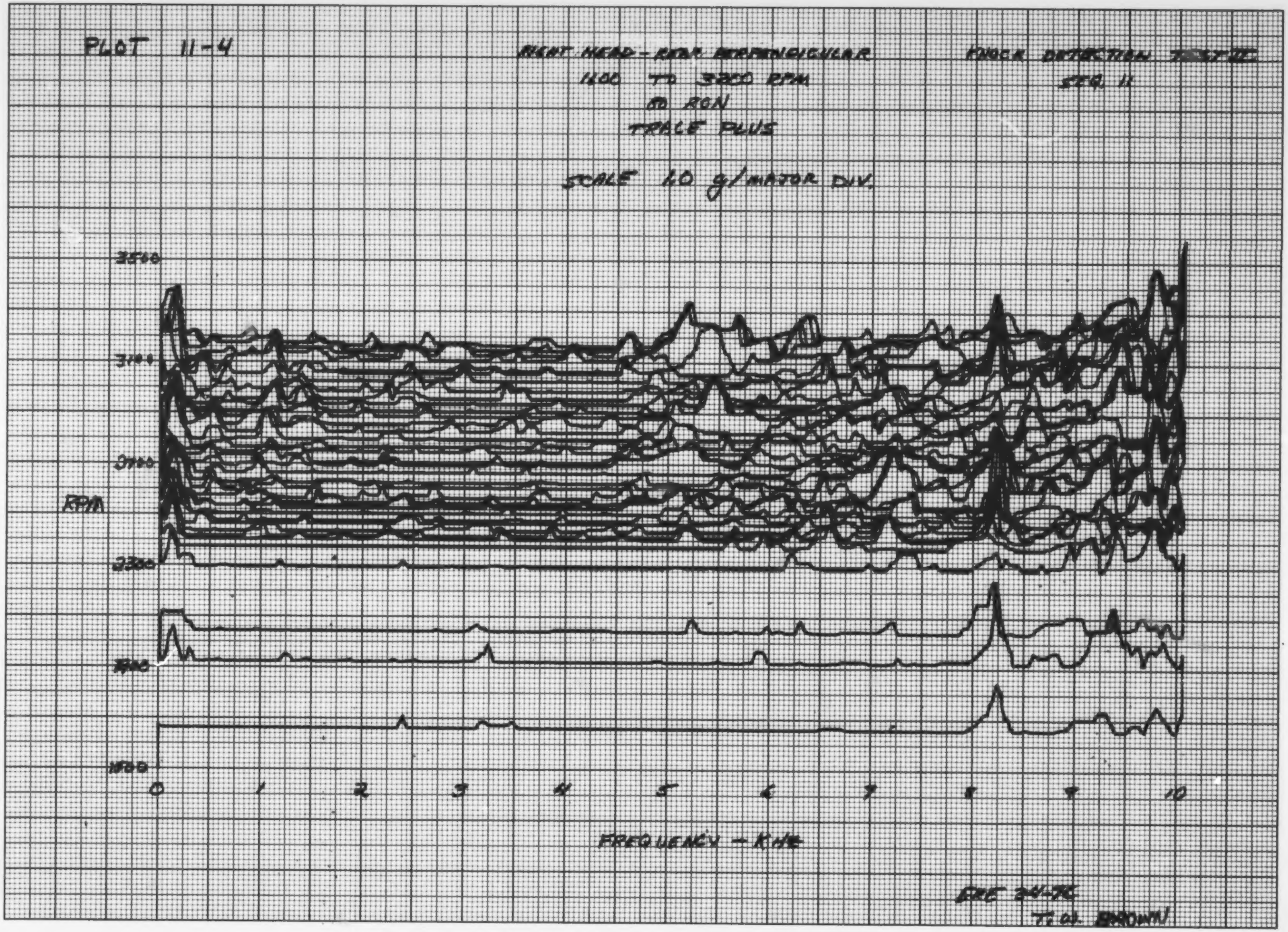
PLOT 11-3

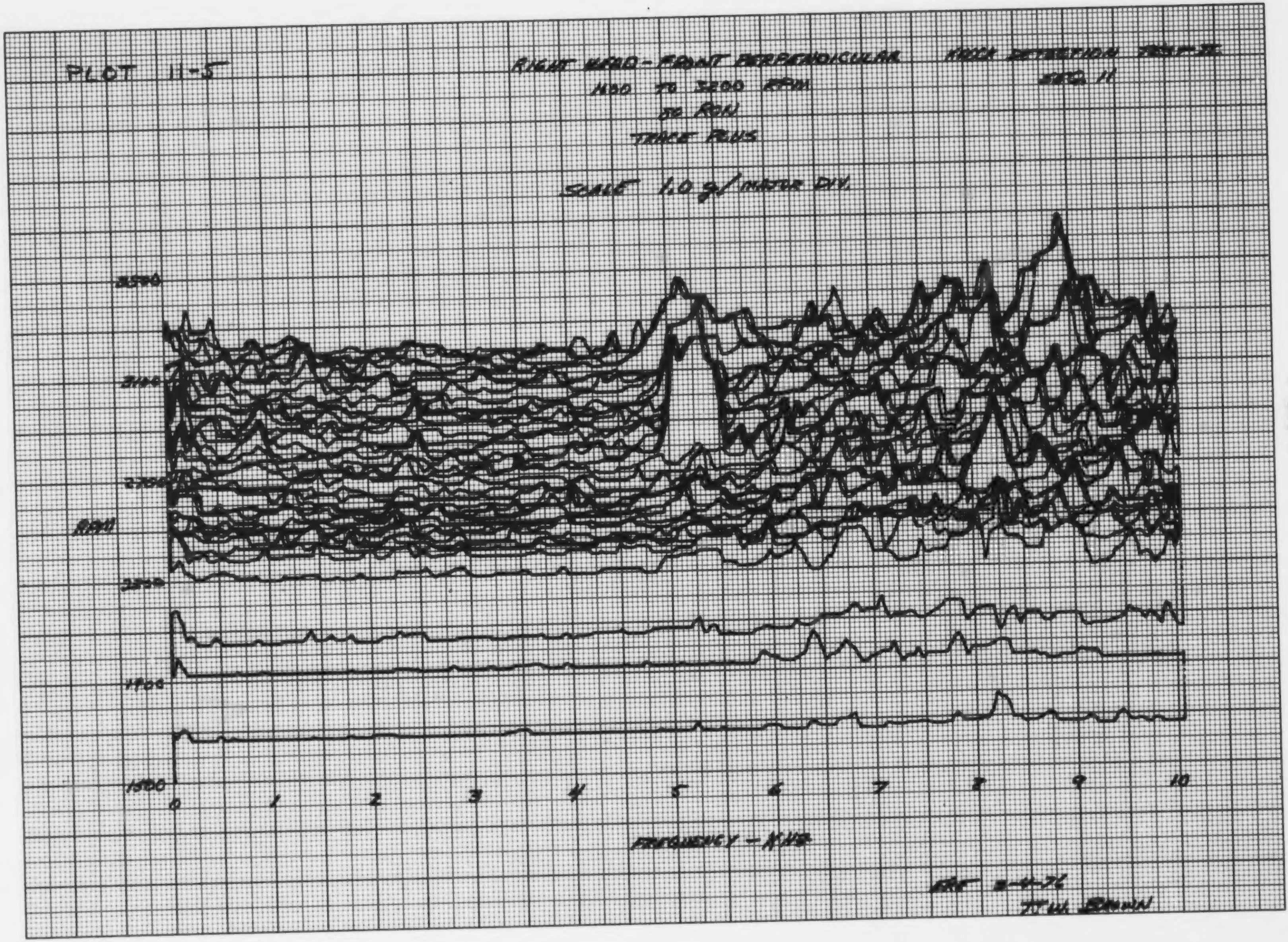
OIL PAN (INSIDE) PERPENDICULAR
1600 TO 3800 RPM
80 RON
TRACE PLUS

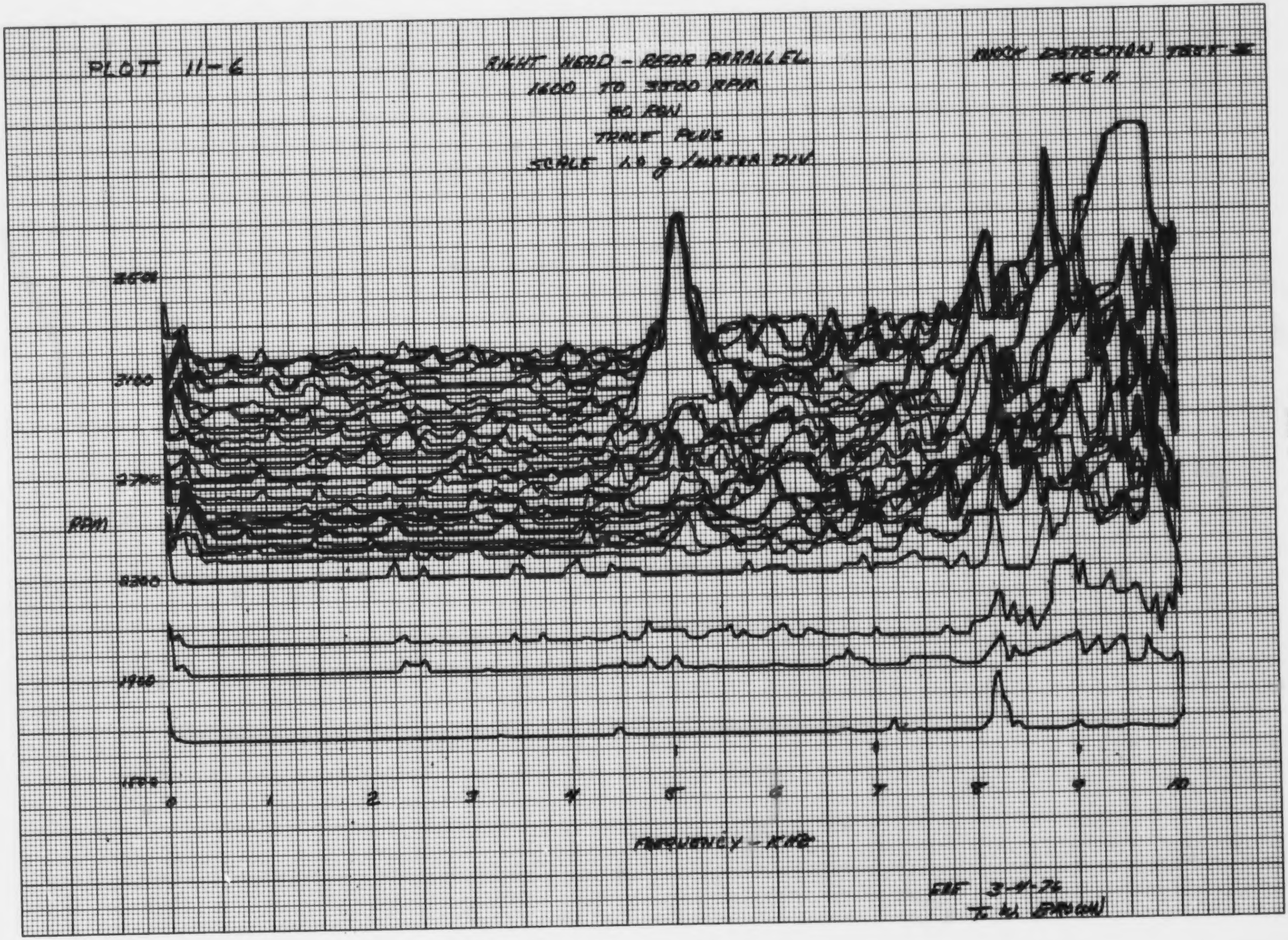
KNOCK DETECTION TEST II
SEQ. 11

SCALE 1.0 g/MAJOR DIV.

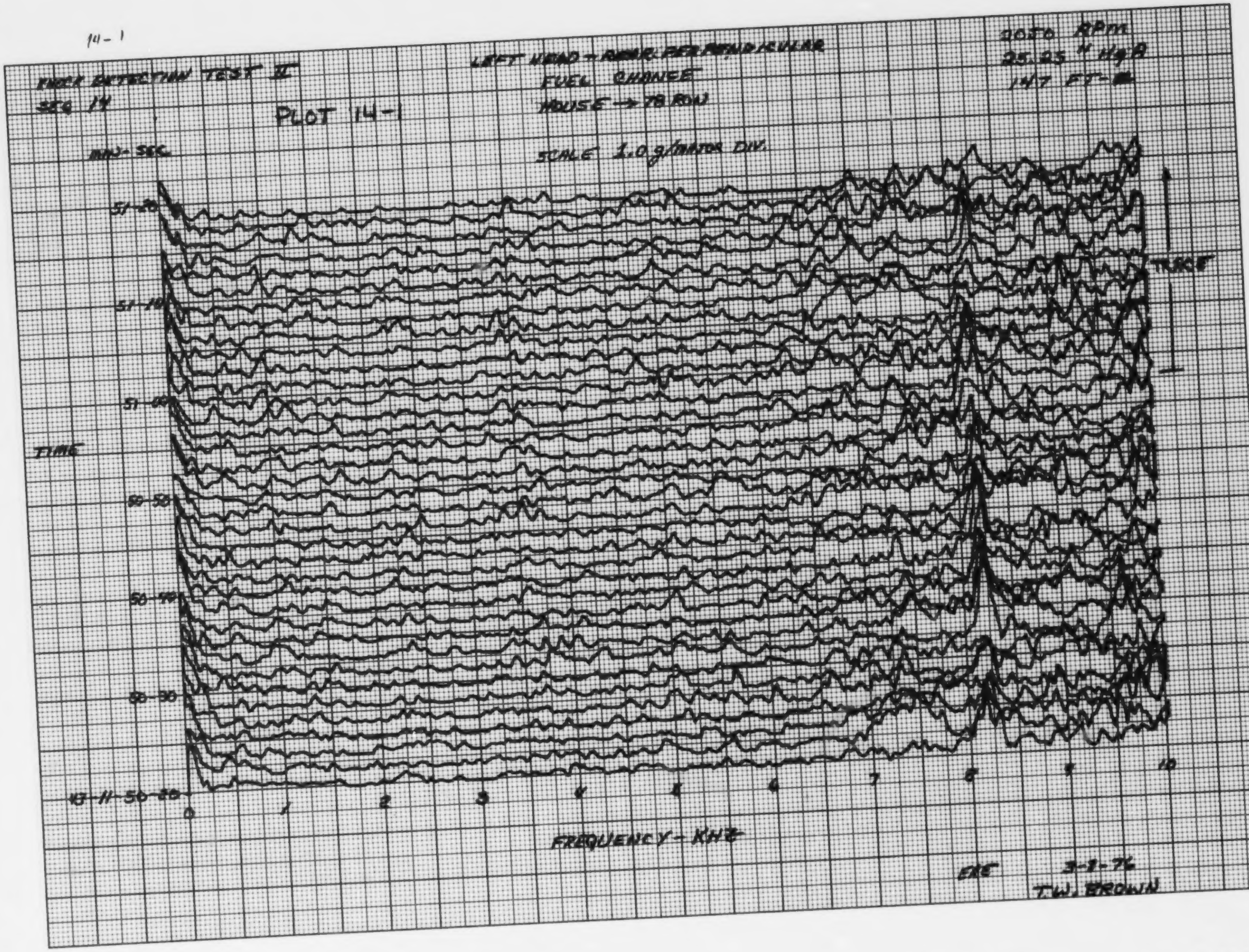
ARE 3-4-76
T.W. BROWN

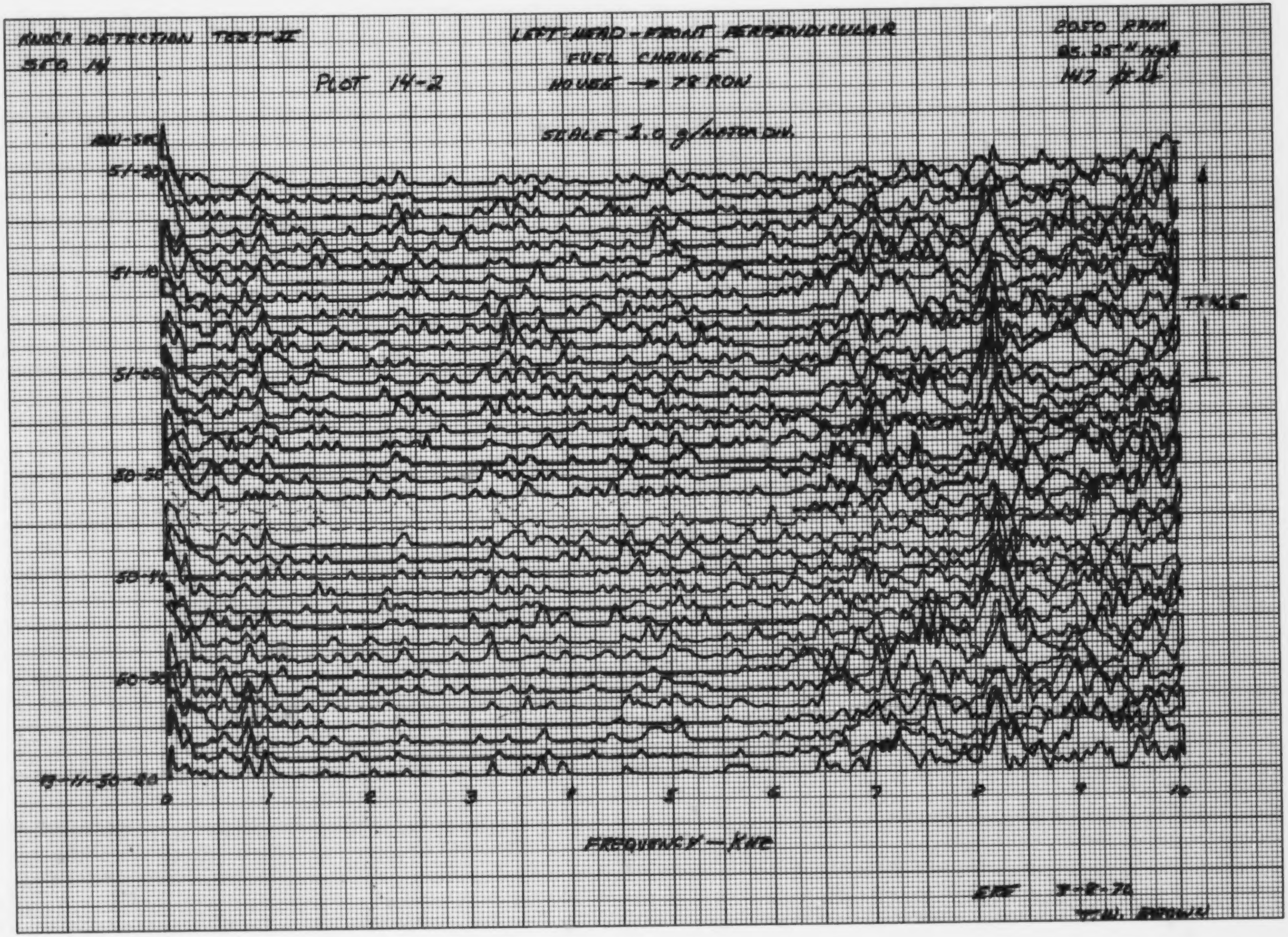

PLOT 11-4
RIGHT HEAD - REAR PERPENDICULAR
1600 TO 3300 RPM
90 RON
TRACE PLUS
SCALE 1.0 g/MAJOR DIV.
KNOCK DETECTION TEST III
SEQ. 11
3500
3100
2700
RPM
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHz
ERC 2-4-76
T. W. BROWN

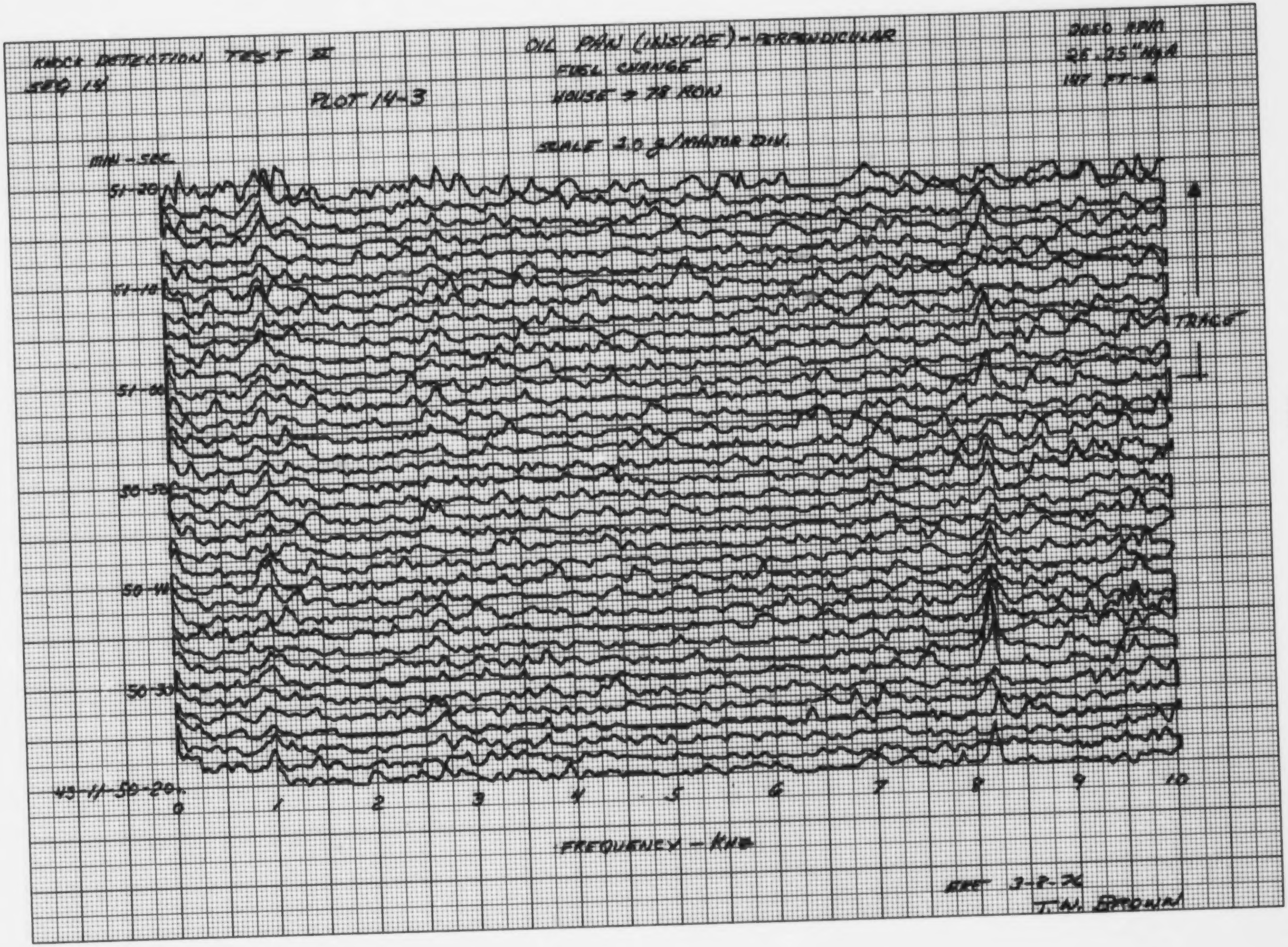

PLOT 11-5
RIGHT HEAD - FRONT PERPENDICULAR
1400 TO 3200 RPM
50 RPM
TRACE PLUS
SCALE 1.0 g/ MAJOR DIV.
KNOCK DETECTION TEST II
SEQ. 11
3500
3100
2700
RPM
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHZ
VRF 8-4-76
T.W. BROWN

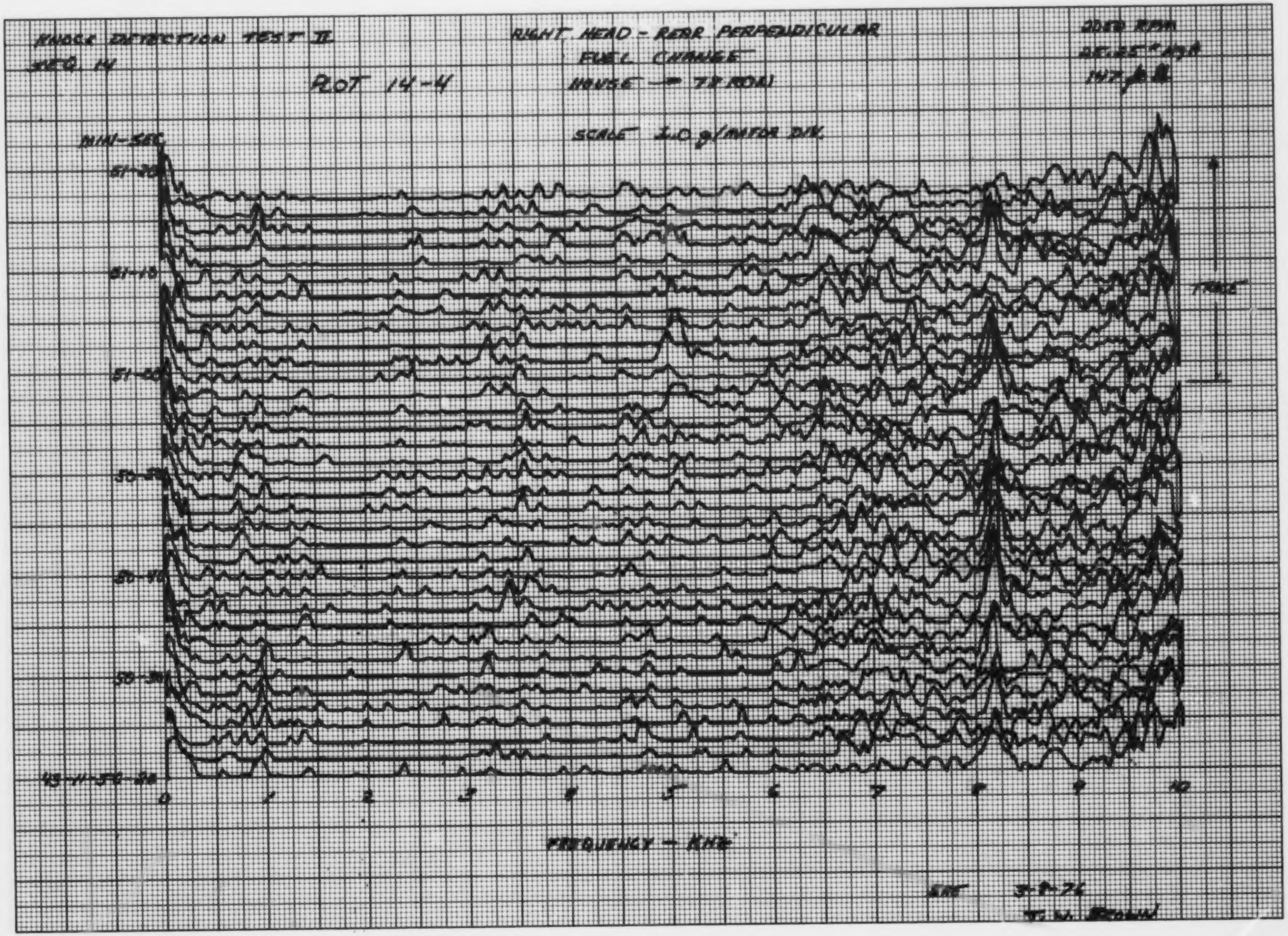

PLOT 11-6
RIGHT HEAD - REAR PARALLEL
1600 TO 3700 RPM
80 RPM
TRACE PLUS
SCALE 1.0 g/MAJOR DIV
KNOCK DETECTION TEST II
SEC A
3500
3100
2700
RPM
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHZ
EBF 3-4-74
To H. BROWN

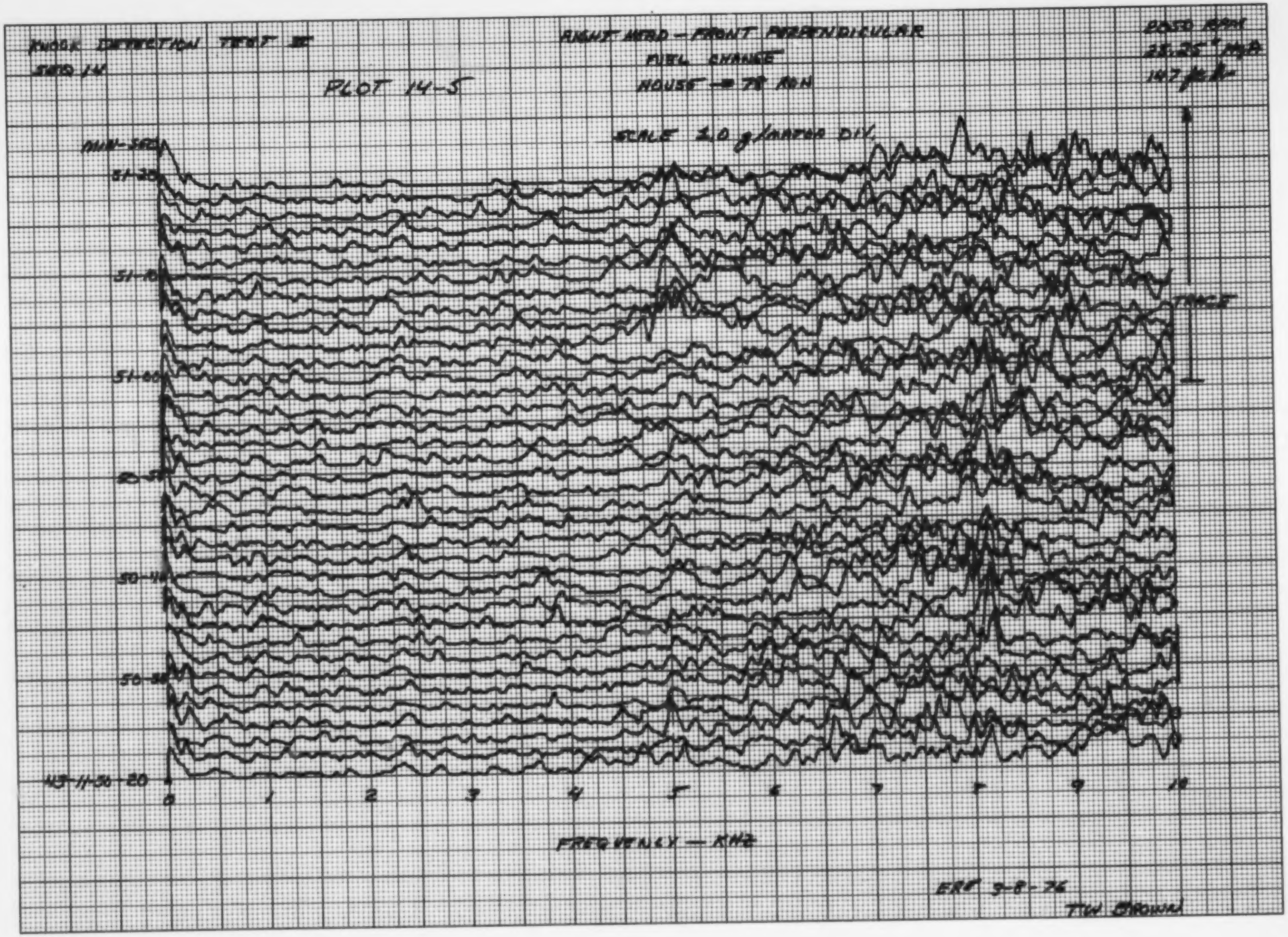
14-1

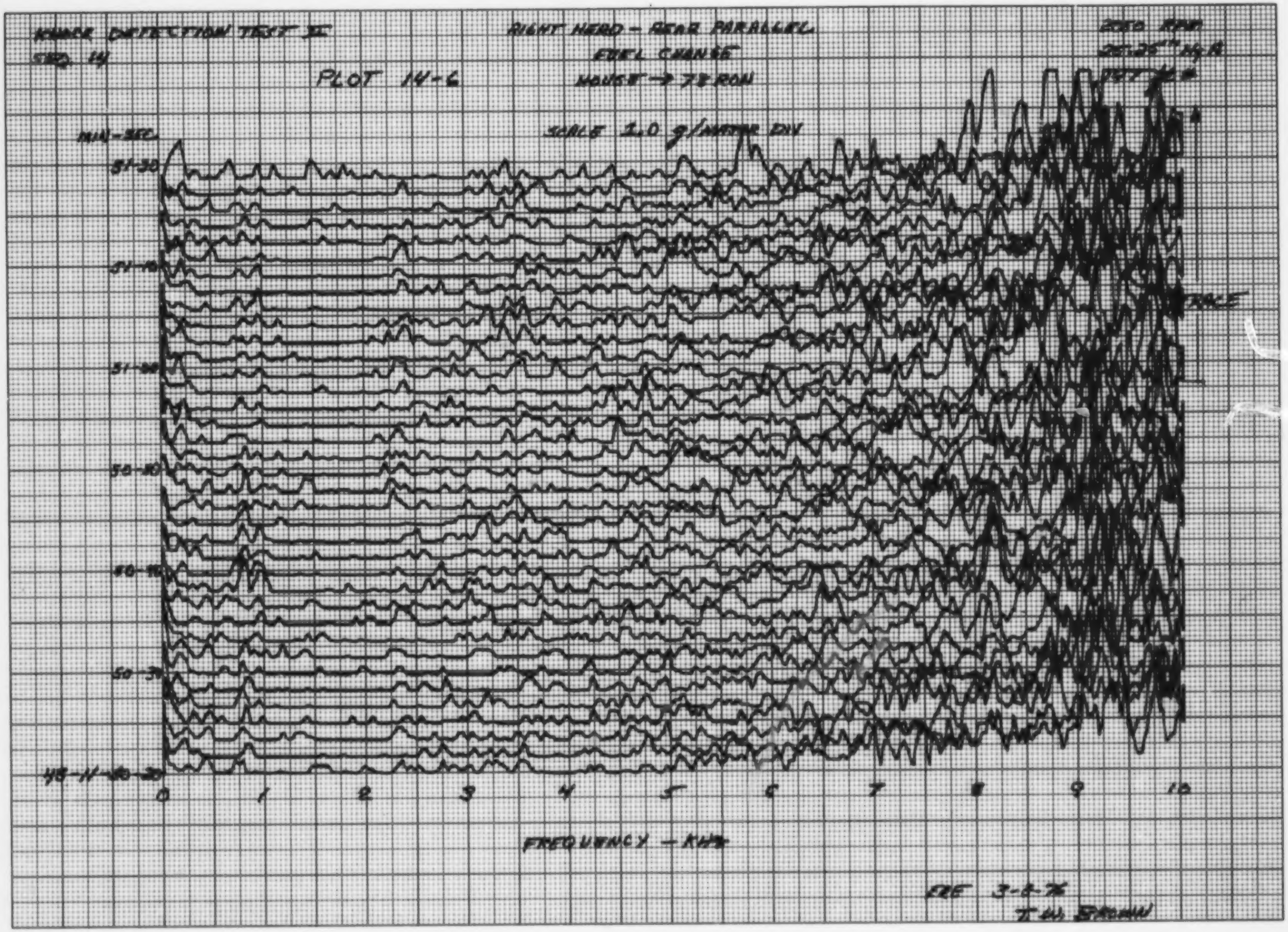

KNOCK DETECTION TEST II
SEQ 14
PLOT 14-1
LEFT HEAD - REAR: PERPENDICULAR
FUEL CHANGE
HOUSE → 78 RON
SCALE 1.0 g/MAJOR DIV.
2050 RPM
25.25" HgA
147 FT-LB
MIN-SEC
TIME
51-20
51-10
51-00
50-50
50-40
50-30
13-11-50-20
0
1
2
3
4
5
6
7
8
9
10
TRACE
FREQUENCY - KHZ
ERE
3-2-76
T.W. BROWN

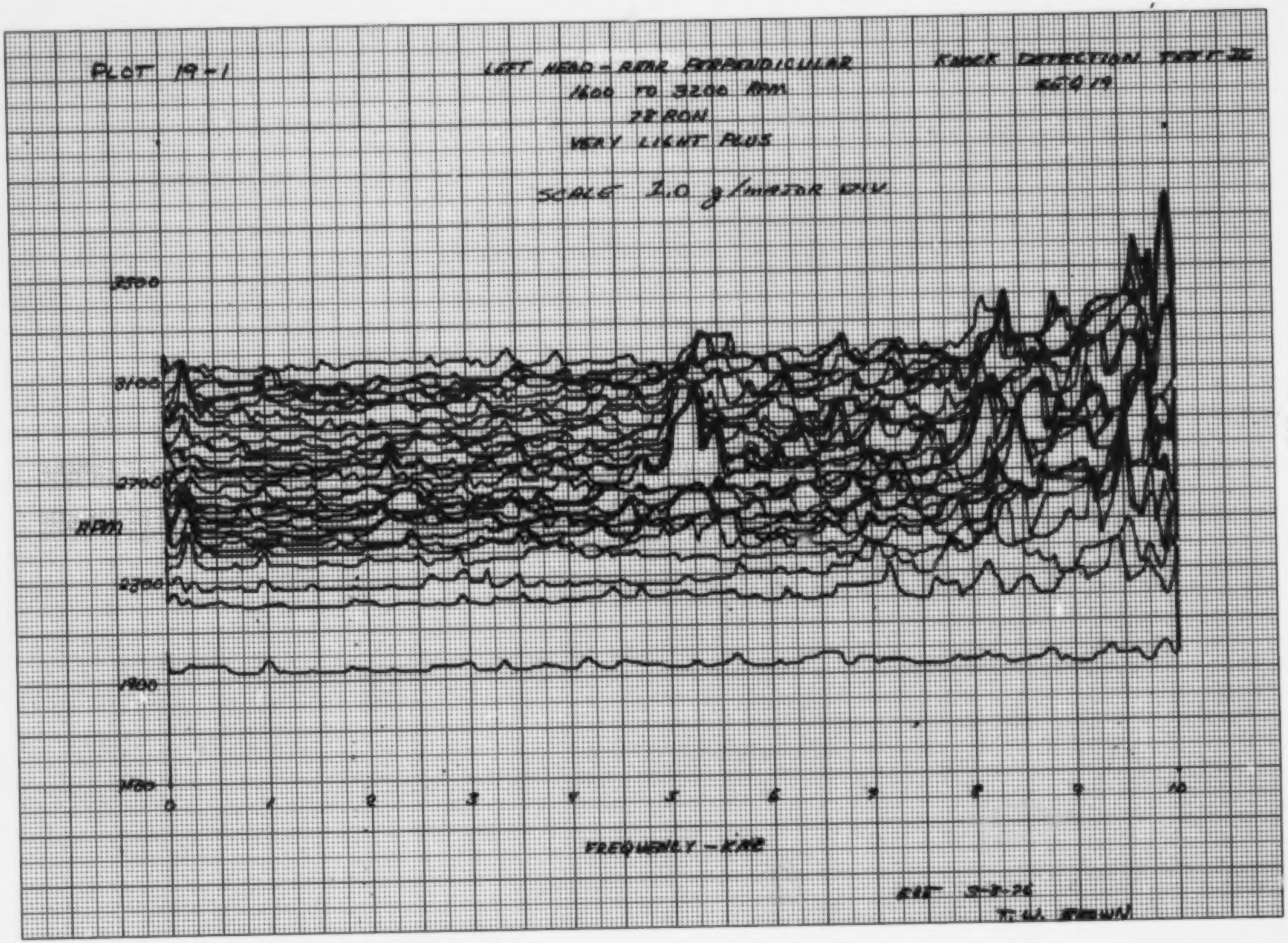

KNOCK DETECTION TEST II
SEQ 14
PLOT 14-2
LEFT HEAD - FRONT PERPENDICULAR
FUEL CHANGE
HOUSE → 78 RON
SCALE 1.0 g/MAJOR DIV.
2050 RPM
25.25" HgA
M7 #II
MIN-SEC
51-20
51-10
51-00
50-50
50-40
50-30
13-11-50-20
0
1
2
3
4
5
6
7
8
9
10
TIME
FREQUENCY — KHZ
EAF 3-8-72
T.W. BROWN

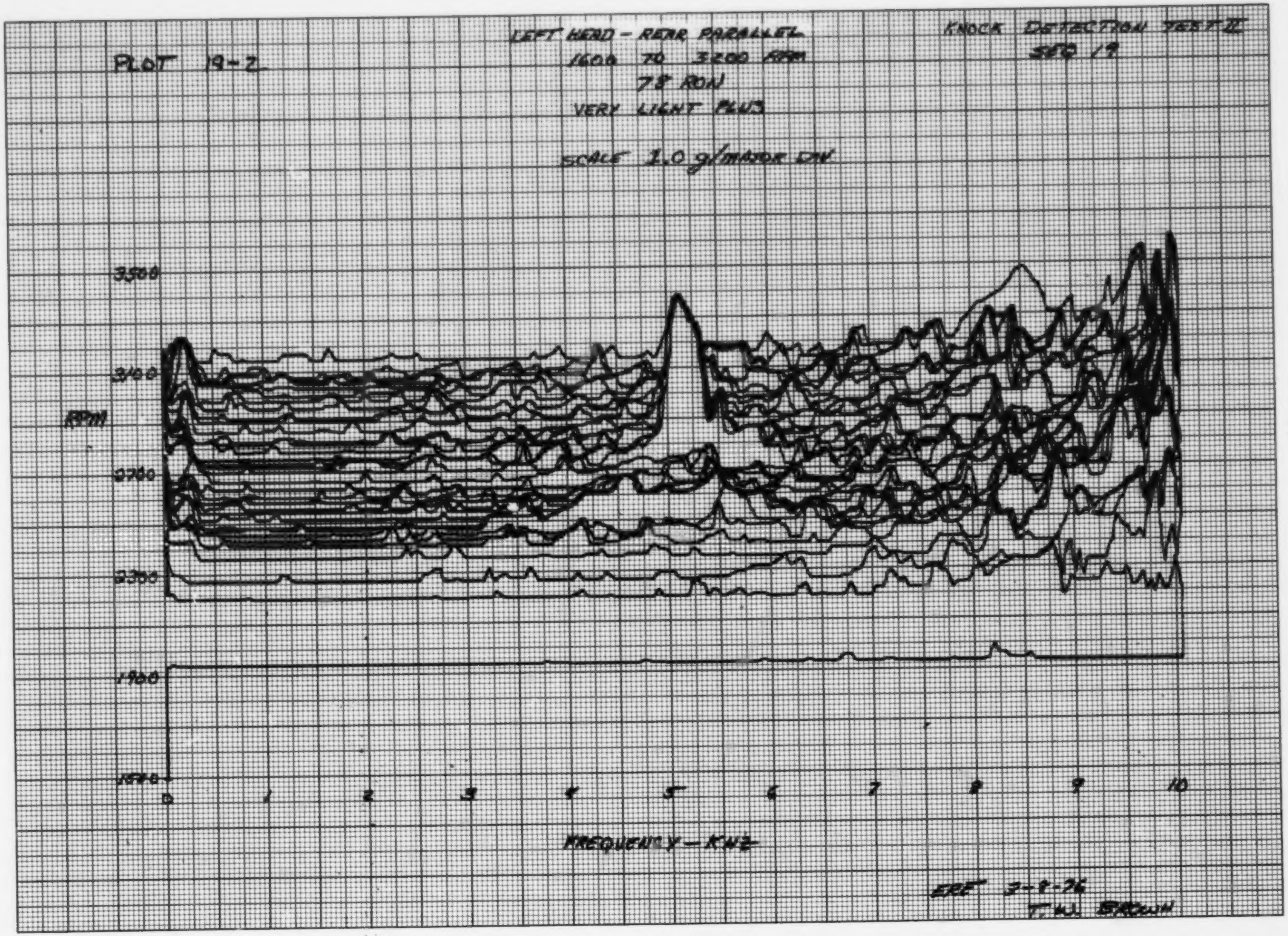

KNOCK DETECTION TEST II
SEQ 14
PLOT 14-3
OIL PAN (INSIDE) - PERPENDICULAR
FUEL CHANGE
HOUSE → 78 RON
2650 RPM
25.25" HgA
147 FT-#
SCALE 1.0 g/MAJOR DIV.
MIN - SEC.
51-20
51-10
51-00
50-50
50-40
50-30
43-11-50-20
TRACE
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHZ
KRE 3-8-76
T.W. BROWN


KNOCK DETECTION TEST II
SEQ. 14
PLOT 14-4
RIGHT HEAD - REAR PERPENDICULAR
FUEL CHANGE
HOUSE → 78 RON
SCALE 1.0 g/MAJOR DIV.
2050 RPM
25.25" HgA
147 ft lb
MIN-SEC
51-30
51-10
51-00
50-50
50-40
50-30
45-11-50-20
TRACE
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHZ
SME
3-9-76
T. W. BROWN

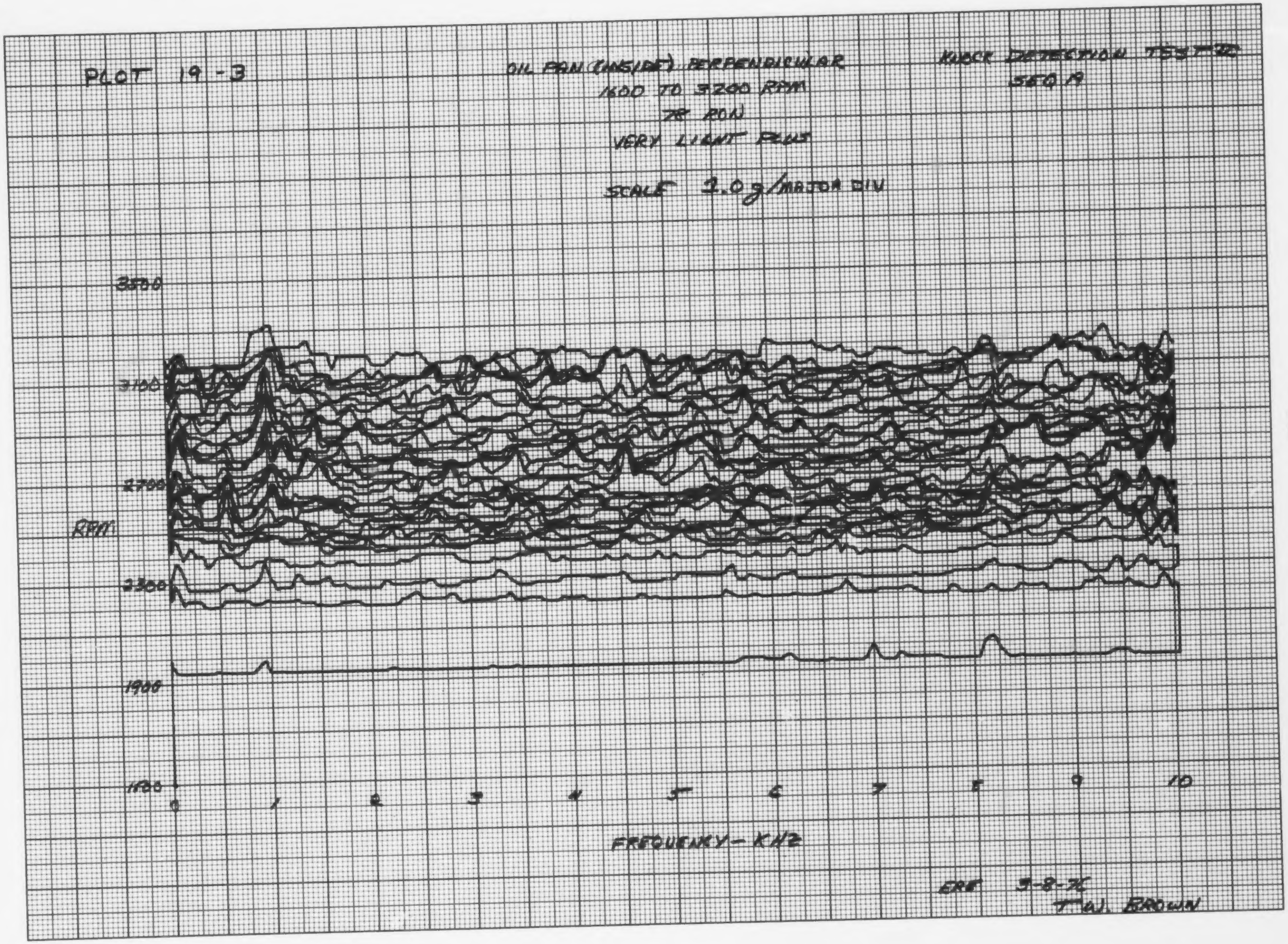

KNOCK DETECTION TEST II
SEQ 14
PLOT 14-5
RIGHT HEAD – FRONT PERPENDICULAR
FUEL CHANGE
HOUSE → 78 RON
2250 RPM
28.25" HgA
147 ft-lb
SCALE 1.0 g/MAJOR DIV.
MIN-SEC
51-20
51-10
51-00
50-50
50-40
50-30
49-11-30-20
TRACE
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY — KHZ
ERF 9-8-76
T.W. BROWN

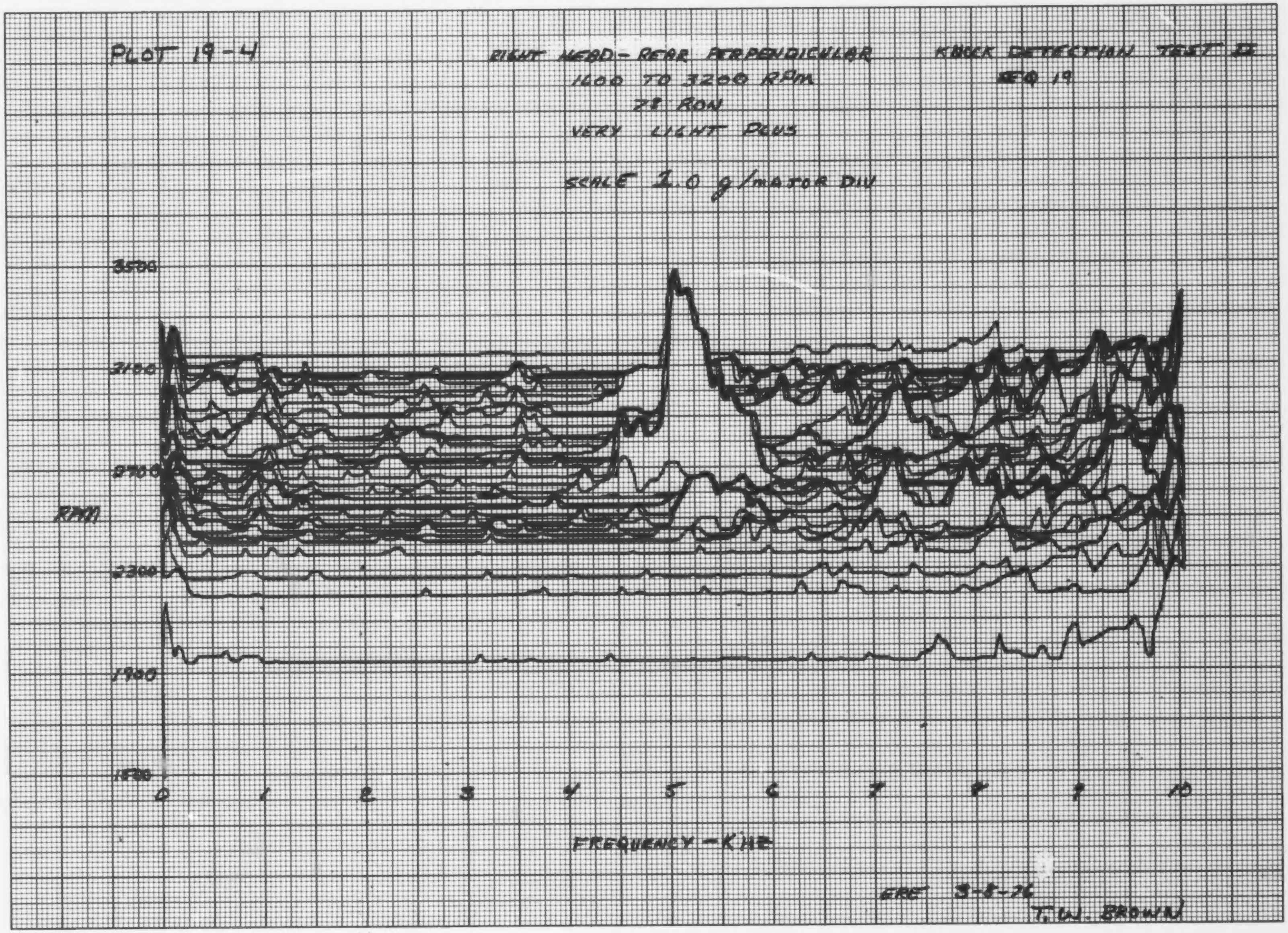

KNOCK DETECTION TEST II
SEQ. 14
PLOT 14-6
RIGHT HEAD - REAR PARALLEL
FUEL CHANGE
HOUSE → 78 RON
SCALE 1.0 g/METER DIV
2050 RPM
25.25" Hg A
TRACE
MIN-SEC
51-30
51-10
51-90
50-10
50-10
50-30
48-11-20-30
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHz
EZE 3-8-76
T. W. BROWN

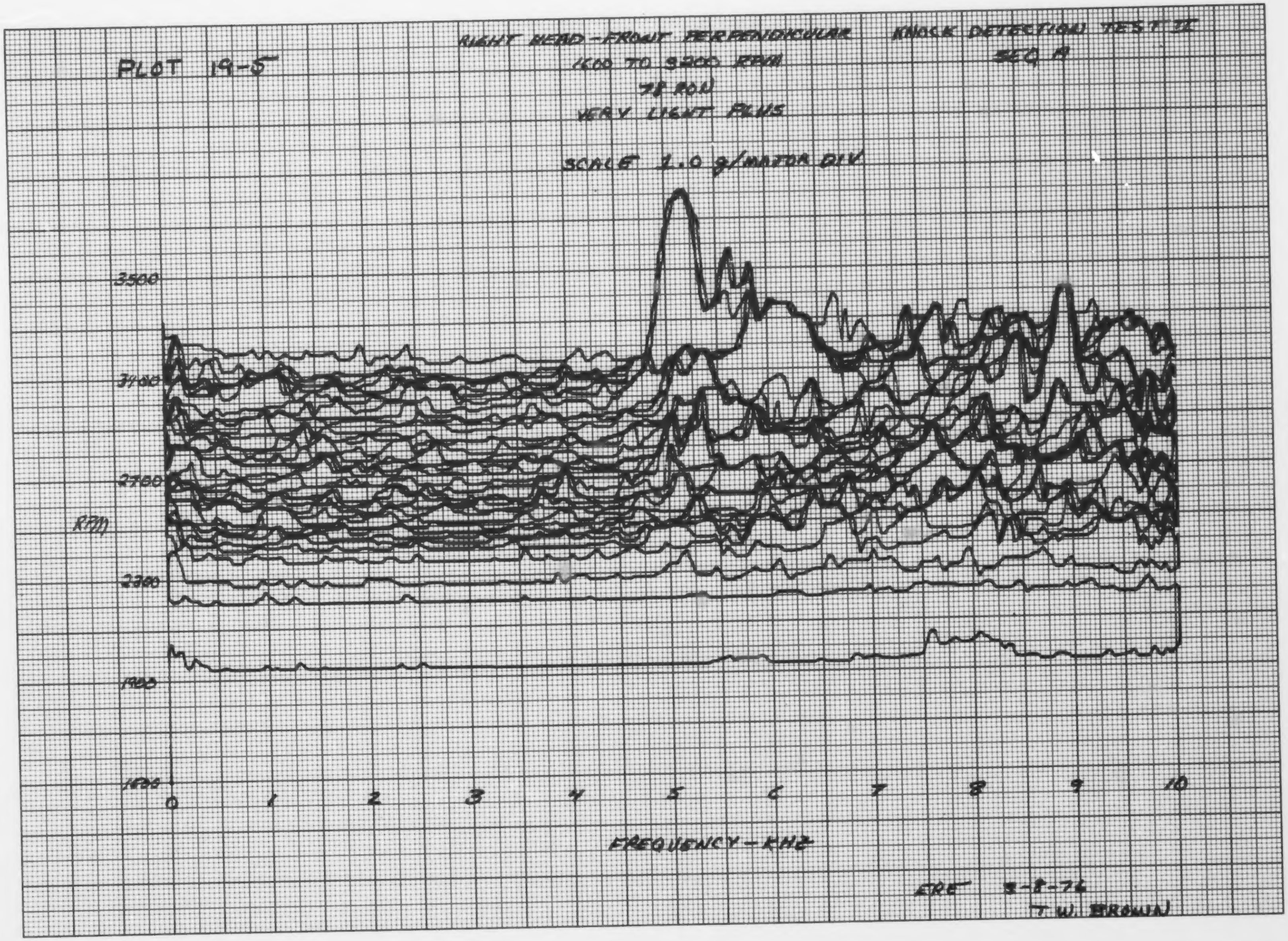

PLOT 19-1
LEFT HEAD - REAR PERPENDICULAR
1600 TO 3200 RPM
72 RON
VERY LIGHT PLUS
SCALE 2.0 g/MAJOR DIV.
KNOCK DETECTION TEST II
SEQ 19
3500
3100
2700
RPM
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHZ
EHE 5-3-76
T. W. BROWN


PLOT 19-2
LEFT HEAD - REAR PARALLEL
1600 TO 3200 RPM
78 RON
VERY LIGHT PLUS
SCALE 1.0 g/MAJOR DIV
KNOCK DETECTION TEST II
SEQ 19
RPM
3500
3100
2700
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY — KHZ
ERE 3-8-76
T.W. BROWN

PLOT 19 - 3


OIL PAN (INSIDE) PERPENDICULAR
1600 TO 3200 RPM
78 RON
VERY LIGHT PLUS
SCALE 2.0 g/MAJOR DIV
KNOCK DETECTION TEST II
SEQ A
3500
3100
2700
RPM
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY – KHZ
ERE 5-8-76
T. W. BROWN


PLOT 19-4
RIGHT HEAD - REAR PERPENDICULAR
1600 TO 3200 RPM
78 RON
VERY LIGHT PLUS
SCALE 1.0 g/MAJOR DIV
KNOCK DETECTION TEST II
SEQ 19
3500
3100
2700
RPM
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHZ
ERE 3-8-76
T. W. BROWN



PLOT 19-5

RIGHT HEAD - FRONT PERPENDICULAR KNOCK DETECTION TEST II
SEQ A
1600 TO 3200 RPM
78 RON
VERY LIGHT PLUS

SCALE 1.0 g/MAJOR DIV.

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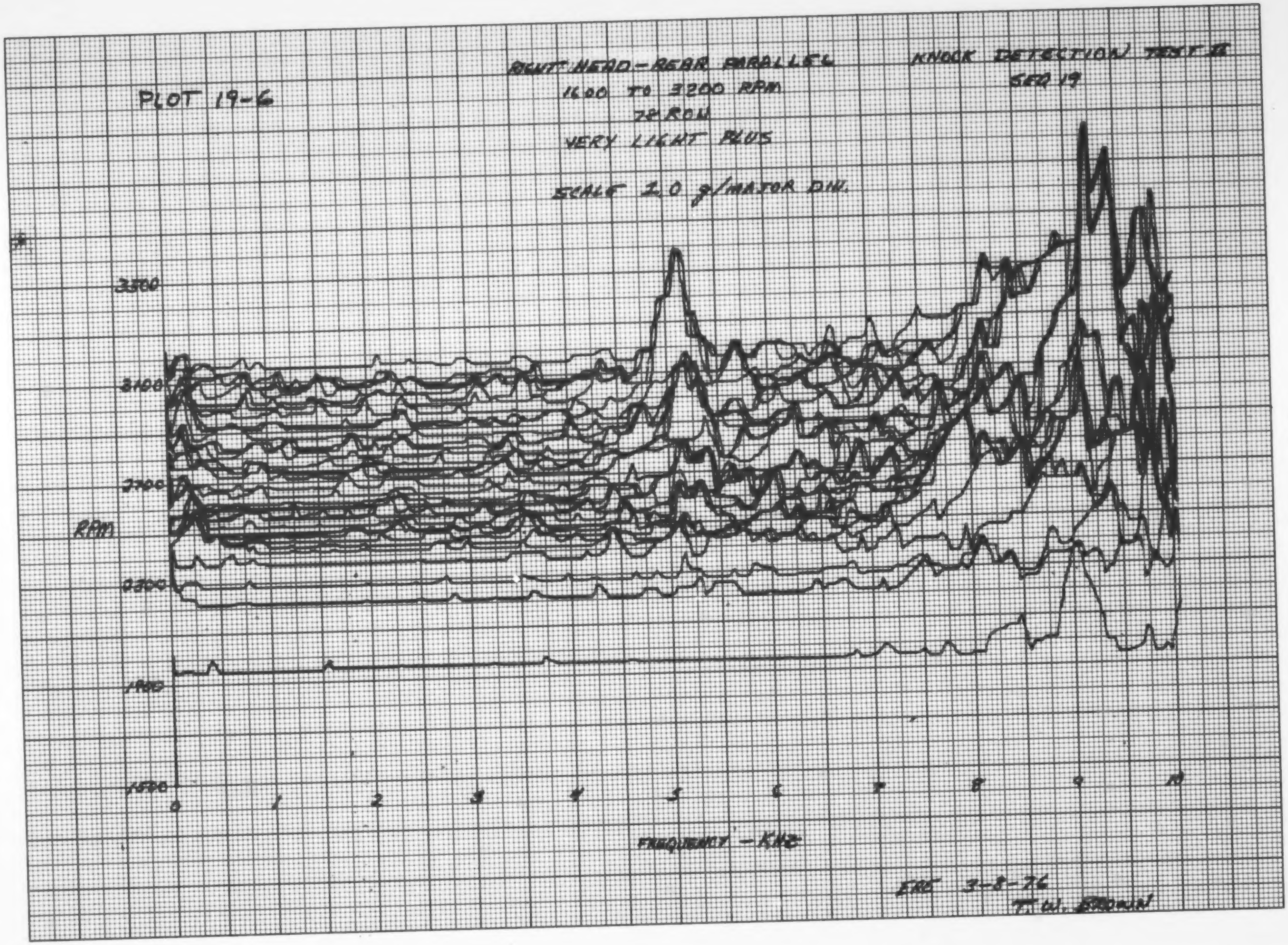
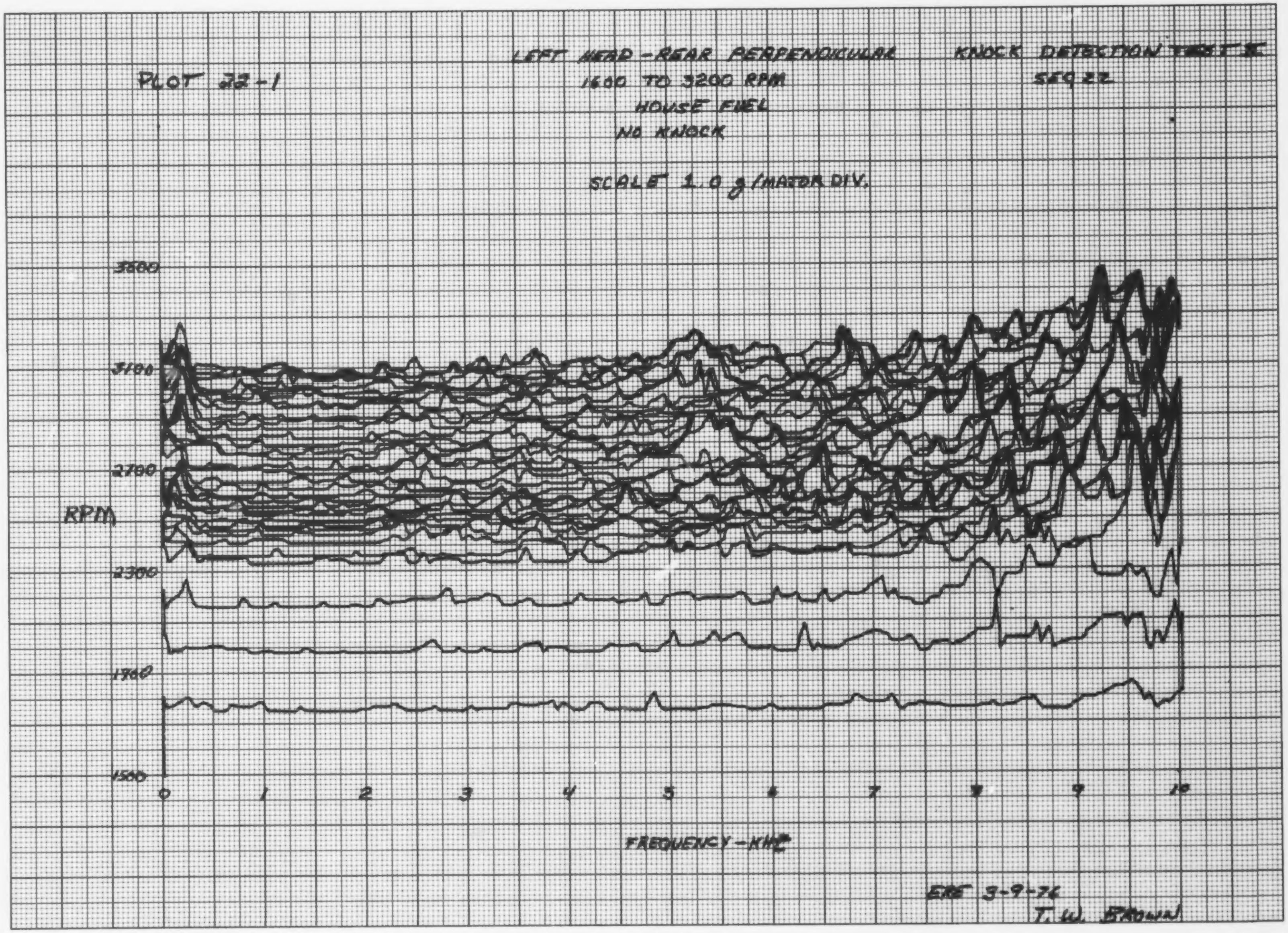
T.W. BROWN


PLOT 19-6
RIGHT HEAD-REAR PARALLEL
1600 TO 3200 RPM
78 RON
VERY LIGHT PLUS
SCALE 2.0 g/MAJOR DIV.
KNOCK DETECTION TEST II
SEQ 19
3500
3100
2700
RPM
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHZ
ERC 3-8-76
T. W. BROWN

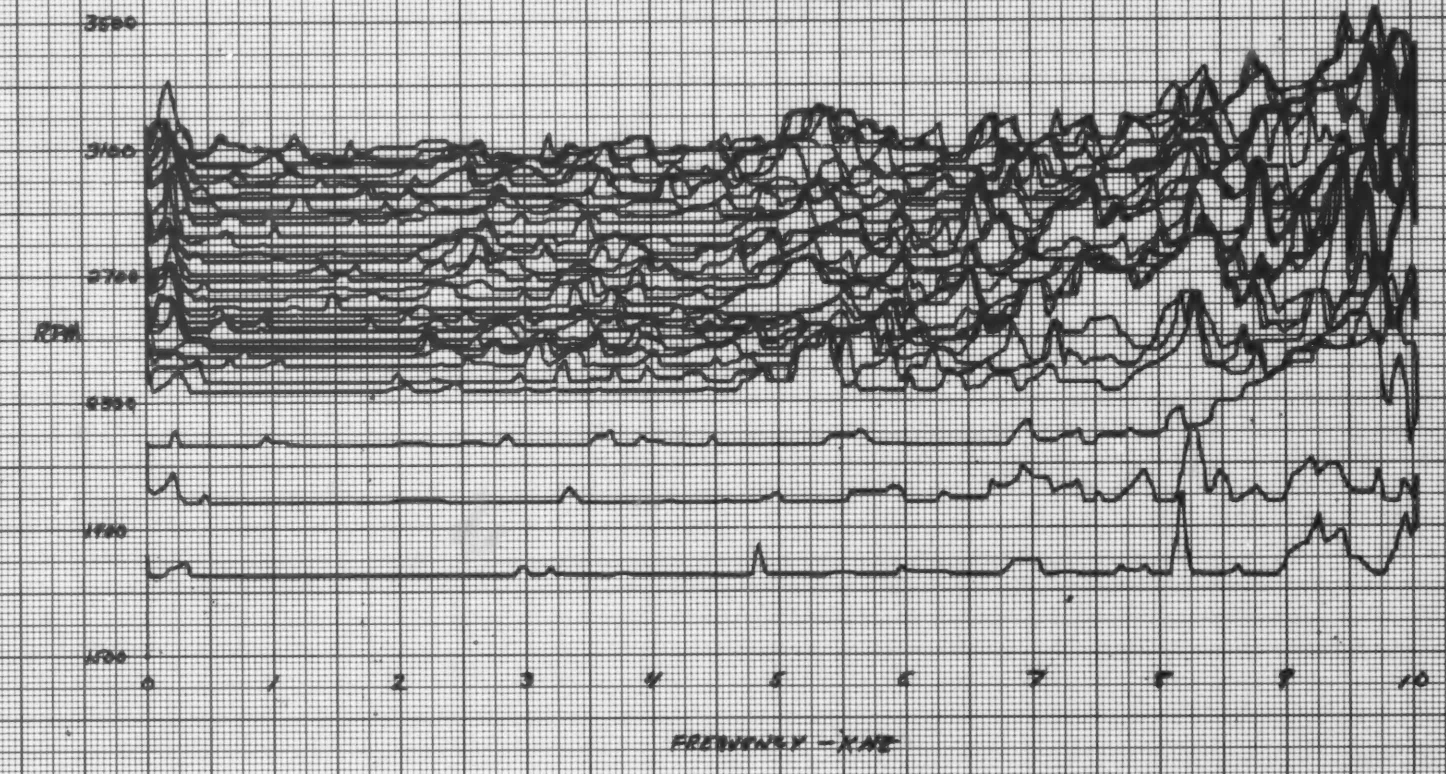

PLOT 22-1
LEFT HEAD - REAR PERPENDICULAR
1600 TO 3200 RPM
HOUSE FUEL
NO KNOCK
KNOCK DETECTION TEST II
SEQ 22
SCALE 1.0 g/MAJOR DIV.
3500
3100
2700
RPM
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHz
ERE 3-9-76
T. W. BROWN

PLOT II-2

LEFT HEAD-REAR PARALLEL
1600 TO 3200 RPM
HOUSE FUEL
NO KNOCK

SCALE 2.0 g/MAJOR DIV

KNOCK DETECTION TEST III
SEQ II



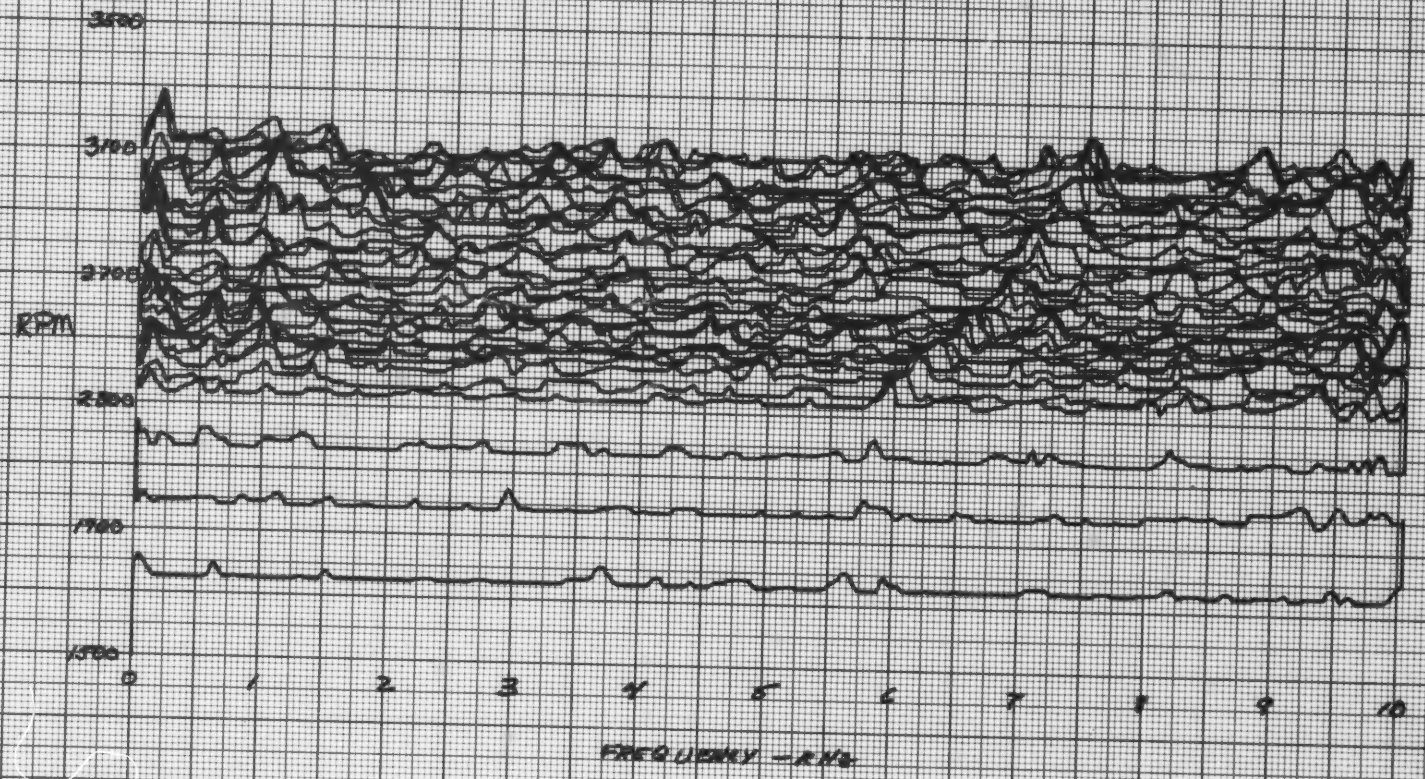
EKE 3-8-76
T. W. Brown

PLOT 22-3

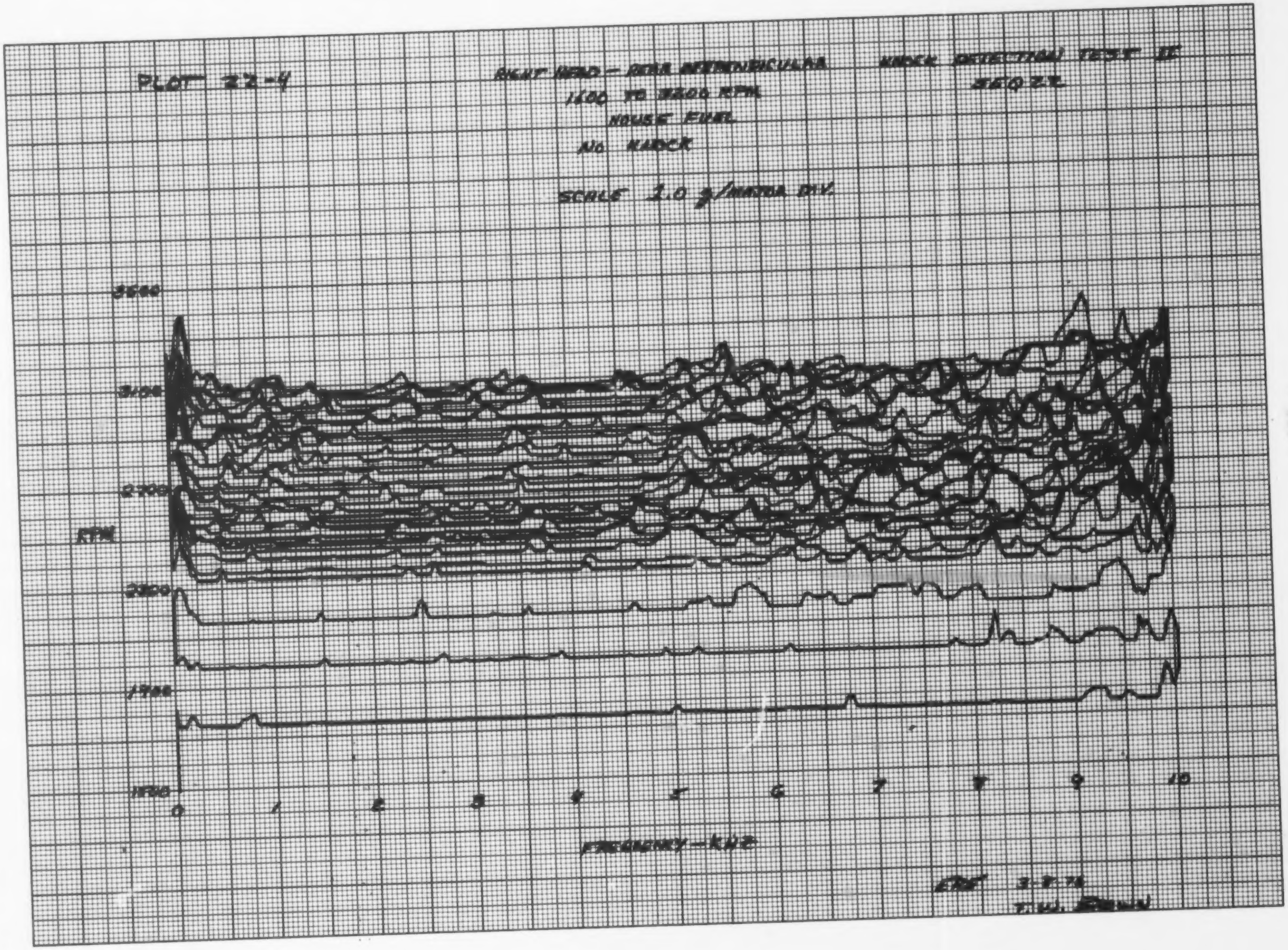
OIL PAN (INSIDE) PERPENDICULAR
1600 TO 3200 RPM
HOUSE FUEL
NO KNOCK

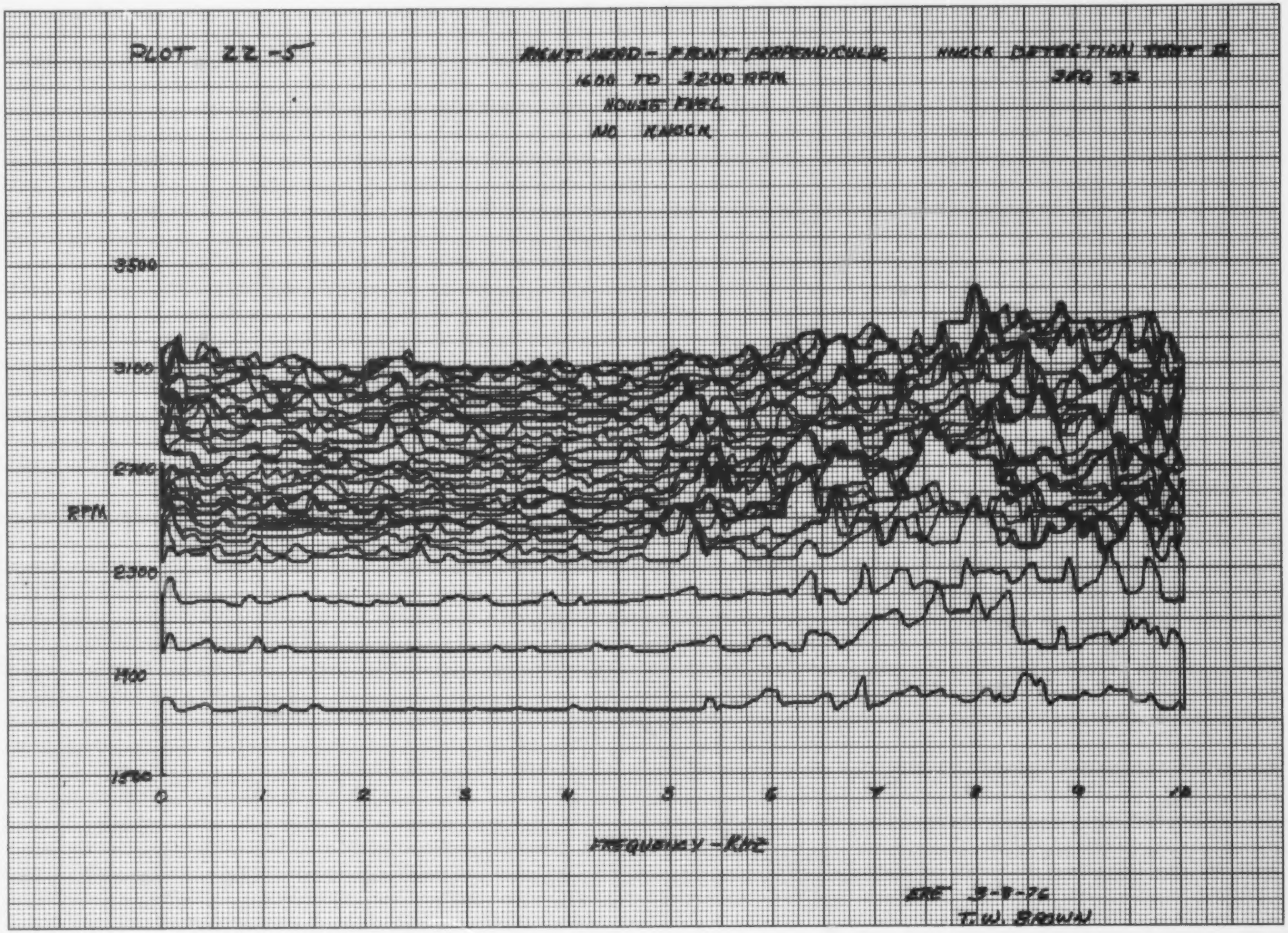
KNOCK DETECTION TEST III
SEQ 22

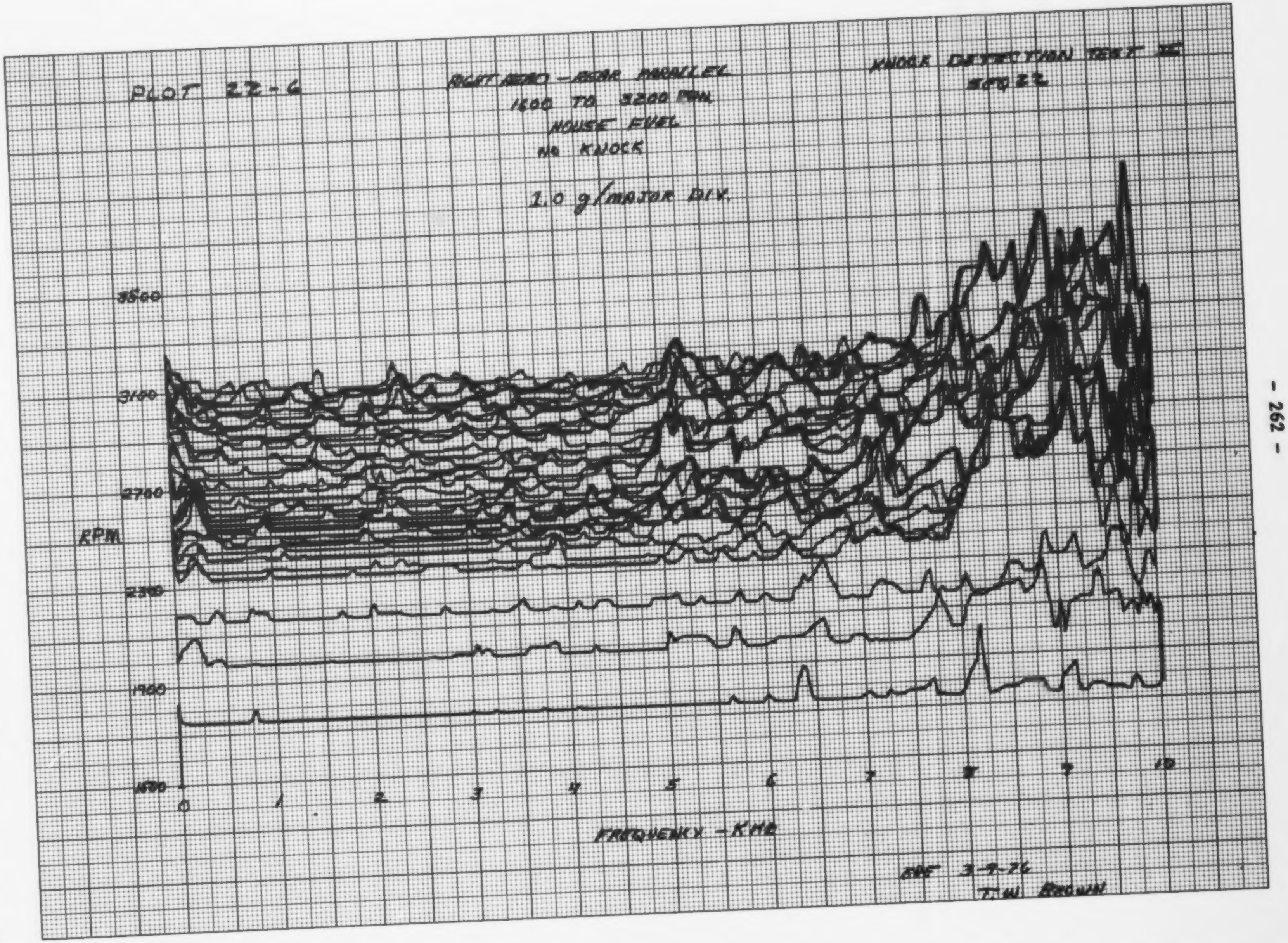
SCALE 1.0 g/MAJOR DIV



3-2-76
T. W. BROWN


PLOT 22-4
RIGHT HEAD — REAR PERPENDICULAR
KNOCK DETECTION TEST II
SEQ 22
1600 TO 3200 RPM
HOUSE FUEL
NO KNOCK
SCALE 1.0 g/MAJOR DIV.
3500
3100
2700
RPM
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY—KHZ
3-8-78
T.W. BROWN


PLOT 22-5
RIGHT HEAD - FRONT PERPENDICULAR
1600 TO 3200 RPM
HOUSE FUEL
NO KNOCK
KNOCK DETECTION TEST II
RUN 22
3500
3100
2700
RPM
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHZ
ERE 3-8-76
T.W. BROWN


PLOT 22-6
RIGHT HEAD - REAR PARALLEL
1600 TO 3200 RPM
HOUSE FUEL
NO KNOCK
1.0 g/MAJOR DIV.
KNOCK DETECTION TEST II
SEQ 22
3500
3100
2700
RPM
2300
1900
1500
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY - KHZ
BNF 3-9-76
T.W. BROWN

APPENDIX B

EMISSIONS AND FUEL ECONOMY OF 1975 CHEVROLET NOVA

APPENDIX B-1

EMISSIONS OF 1975 NOVA

Test Cycle	Mileage (miles/km)	Emissions - g/mile		
		CO	HC	NO_x
CVS-CH	564/907	2.97	0.47	2.64
EPA-H	575/925	0.41	0.35	3.75
CVS-CH	585/941	3.73	0.54	2.39
EPA-H	596/959	0.14	0.22	3.71
CVS-CH	606/975	4.42	0.70	2.30
EPA-H	617/993	0.27	0.13	3.53
CVS-CH	6860/11,040	3.47	0.41	1.77
EPA-H	6871/11,058	0.50	0.28	3.34
CVS-CH	6882/11,076	4.09	0.39	1.84
EPA-H	6893/11,093	0.53	0.24	3.34
CVS-CH	8903/14,328	4.34	0.49	1.80
EPA-H	8915/14,347	0.27	0.14	3.81
CVS-CH	8925/14,363	4.96	0.43	1.61
EPA-H	8936/14,381	0.37	0.20	3.36
CVS-CH	11,025/17,743	6.16	0.48	2.33
EPA-H	11,036/17,761	0.70	0.23	4.58
CVS-CH	11,046/17,777	4.96	0.49	2.02
EPA-H	11,058/17,796	0.31	0.14	3.71
CVS-CH	13,148/21,160	4.32	0.49	2.23
EPA-H	13,159/21,177	0.62	0.21	5.73
CVS-CH	13,170/21,195	4.33	0.44	2.18
EPA-H	13,181/21,213	0.68	0.17	4.74
CVS-CH	13,191/21,229	5.50	0.51	2.34
EPA-H	13,202/21,247	0.71	0.23	4.93

APPENDIX B-2

Test		Mileage	Emissions - g/Mile			Remarks
No.	Cycle	(Miles/km)	CO	HC	NO_x	
1	CVS-CH	13,947/22,441	34.8	2.37	2.27	Engine Out
	HFET	13,958/22,458	45.4	1.22	2.30	" "
2	CVS-CH	13,968/22,475	30.9	2.19	1.92	" "
	HFET	13,979/22,492	18.0	0.75	2.83	" "
3	CVS-CH	13,994/22,516	40.1	1.97	1.77	" "
	HFET	14,005/22,534	39.6	1.37	1.96	" "
4	CVS-CH	14,015/22,550	3.99	0.57	1.76	With Catalyst
	HFET	14,026/22,568	0.09	0.08	1.66	" "
5	CVS-CH	14,048/22,603	4.83	0.58	1.79	" "
	HFET	14,059/22,621	0.45	0.12	1.95	" "
6	CVS-CH	14,072/22,642	7.23	0.51	1.51	" "
	HFET	14,082/22,658	0.36	0.10	1.59	" "
7	CVS-CH	14,094/22,677	7.86	0.50	1.63	" "
	HFET	14,105/22,695	0.21	0.09	1.64	" "
8	CVS-CH	14,234/22,902	9.22	0.71	2.45	Catalyst, 9:1 C.R.
	HFET	14,245/22,920	0.22	0.11	2.08	" "
9	CVS-CH	14,257/22,940	9.00	0.66	2.55	" "
	HFET	14,268/22,957	0.23	0.11	2.16	" "
10	CVS-CH	14,280/22,977	8.62	0.59	2.20	" "
	HFET	14,290/22,993	0.46	0.15	1.92	" "
11	CVS-CH	14,457/23,261	5.60	0.50	1.76	" "
	HFET	14,468/23,279	0.15	0.11	1.64	" "

APPENDIX B-3

		Mileage (miles/km)	Emissions - g/Mile CO	HC	NO$_x$	Remarks
	CVS-CH	14,234 to	8.11	0.62	2.24	Average of 4 Tests with
	HFET	14,468	0.26	0.12	1.95	Standard Recycle
1	CVS-CH	14,480/23,303	5.41	0.50	1.94	GM Proportional EGR Valve
	HFET	14,491/23,320	0.15	0.10	1.76	with 1/4 inch Orifice
2	CVS-CH	14,503/23,340	10.53	0.61	2.08	GM Proportional EGR Valve
	HFET	14,514/23,357	0.39	0.12	1.86	with 1/4 inch Orifice
3	CVS-CH	14,525/23,375	9.11	0.62	2.26	GM Proportional EGR Valve
	HFET	14,536/23,393	0.32	0.12	1.76	with 1/4 inch Orifice
	CVS-CH		8.35	0.58	2.09	Average of Tests 1 to 3
	HFET		0.29	0.11	1.79	Average of Tests 1 to 3
4	CVS-CH	14,549/23,414	1.75	0.41	2.16	Prop. EGR, Leaner Choke,
	HFET	14,560/23,431	0.12	0.11	1.71	Intake Man. Air Leak
5	CVS-CH	14,572/23,451	1.47	0.36	2.49	Prop. EGR, Leaner Choke,
	HFET	14,583/23,468	0.05	0.11	2.23	Intake Man. Air Leak
6	CVS-CH	14,640/23,560	3.84	0.48	1.63	Prop. EGR, 21/64 inch Orifice
	HFET	14,651/23,578	0.23	0.12	1.40	Leaner Choke
7	CVS-CH	14,842/23,885	3.35	0.51	1.76	Prop. EGR, 21/64 inch Orifice
	HFET	14,853/23,903	0.22	0.12	1.47	Leaner Choke
8	CVS-CH	15,141/24,366	4.56	0.54	1.78	Prop. EGR, 21/64 inch Orifice
	HFET	15,152/24,384	0.48	0.16	1.33	Leaner Choke
	CVS-CH		3.92	0.51	1.72	Average of Tests 6 to 8
	HFET		0.31	0.13	1.40	

APPENDIX B-4

Cycle	Mileage (miles/km)	Emissions - g/mile CO	HC	NO_x	Remarks
CVS-CH	16,549/26,627	6.83	0.95	2.32	Pistons replaced, 350 mi. break-in, prop. EGR valve
HFET	16,560/26,645	0.28	0.23	2.06	
CVS-CH	16,576/26,671	5.24	0.87	2.66	Richer idle mixture. Sample valves on intake manifold plugged.
HFET	16,587/26,688	0.37	0.18	2.46	

APPENDIX B-5

Cycle	(Miles/km)	Emissions - g/mile			Remarks
		CO	HC	NO_x	
CVS-CH	16,784/27,005	7.01	0.69	2.45	New intake manifold gasket.
HFET	16,795/27,023	0.37	0.17	2.65	
CVS-CH	16,824/27,070	6.05	0.92	2.96	Fresh oxidation catalyst. Idle mixture reset.
HFET	16,835/27,088	0.43	0.26	2.58	
CVS-CH	18,283/29,417	6.57	0.72	2.01	Put back old piston, 1200 mi. break-in.
HFET	18,294/29,435	0.32	0.11	1.79	
CVS-CH	18,304/29,451	6.28	0.70	1.83	Repeat.
HFET	18,315/29,469	0.26	0.11	1.57	

APPENDIX B-6

Test	Cycle	Miles/km	Emissions - g/mile CO	HC	NO_x	Remarks
1	CVS-CH	18,328/29,490	4.68	0.96	2.05	Leaner choke; two stalls
	HFET	18,339/29,507	0.42	0.18	2.04	
2	CVS-CH	18,357/29,536	6.12	1.16	1.83	Deposits cleaned, richer choke, false start
	HFET	18,368/29,554	0.24	0.12	1.85	
3	CVS-CH	18,378/29,570	8.52	0.72	1.83	Fast idle increased, 1 stall
	HFET	18,389/29,588	0.67	0.16	1.53	
4	CVS-CH	18,449/29,684	6.89	0.60	1.87	Carburetor rebuilt
	HFET	18,461/29,704	0.35	0.15	1.85	
5	CVS-CH	18,475/29,726	4.39	0.59	2.11	Leaner choke
	HFET	18,486/29,744	0.20	0.13	2.01	
6	CVS-CH	18,581/29,897	5.36	0.65	1.91	Repeat - Weekend Soak
	HFET	18,592/29,915	0.20	0.14	1.90	
7	CVS-CH	18,665/30,032	3.16	0.53	2.07	Repeat
	HFET	18,676/30,050	0.22	0.13	2.03	
8	CVS-CH	18,723/30,125	2.94	0.45	2.08	Repeat
	HFET	18,734/30,143	0.50	0.44	2.25	

APPENDIX B-7

Cycle	Miles/km	Emissions, g/mile			Remarks
		CO	HC	NO_x	
CVS-CH	18,774/30,207	4.09	0.62	1.86	Repeat of Previous Run
HFET	18,785/30,225	0.25	0.14	1.96	
CVS-CH	19,689/31,680	4.74	0.76	1.58	Knock Sensor on - Retarded
HFET	19,700/31,697	0.42	0.35	1.82	3 times on CVS-CH, 8 times on HFET

APPENDIX B-8

Cycle	Miles/km	Emissions g/Mile			Remarks
		CO	HC	NO_x	
CVS-CH	21,638/34,816	6.48	0.81	1.07	New heads installed
HFET		0.55	0.25	1.08	
CVS-CH	21,765/35,020	7.09	1.30	1.46	Hard starting
HFET		0.85	0.56	1.70	
CVS-CH	21,803/35,081	4.28	0.84	2.41	1/4" EGR orifice
HFET		0.75	0.26	3.00	
CVS-CH	21,886/35,215	3.48	0.81	2.64	1/4" EGR orifice, choke richer
HFET		0.51	0.24	2.64	
CVS-CH	21,947/35,313	5.49	0.90	1.86	5/16" EGR orifice, false start
HFET		0.66	0.25	1.92	
CVS-CH	21,976/35,359	10.00	3.46	1.90	5/16" EGR orifice, false start
HFET		0.51	0.19	1.96	
CVS-CH	22,039/35,461	5.29	0.89	2.15	New carb. needle and seat 5/16" EGR
HFET		0.29	0.15	2.19	
CVS-CH	22,088/35,540	4.05	0.71	2.07	Repeat - 5/16" EGR
HFET		0.42	0.24	2.08	

APPENDIX B-9

Cycle	Miles/km	Emissions - g/Mile CO	 HC	 NO_x	Remarks
CVS-CH	22,141/35,625	4.81	0.64	1.95	21/64" EGR orifice
HFET	22,152/35,643	0.30	0.26	2.32	
CVS-CH	22,435/36,098	5.34	0.97	1.77	Repeat, 1 stall
HFET	22,446/36,116	0.29	0.19	2.04	
CVS-CH	22,459/36,137	5.72	0.66	1.86	Repeat
HFET	22,470/36,154	0.40	0.36	2.12	
CVS-CH	22,613/36,384	3.38	0.82	1.84	Repeat
HFET	22,624/36,402	0.10	0.16	2.13	
CVS-CH		4.81	0.77	1.86	Average
HFET		0.27	0.24	2.15	Average
CVS-CH		5.98	0.54	1.67	Average 8:1 Base Case
HFET		0.28	0.10	1.71	Average 8:1 Base Case

APPENDIX B-10

Cycle	Miles/km	Emissions - g/Mile CO	HC	NO_x	Remarks
CVS-CH	29,233/47,036	10.99	0.68	1.31	(6K) No retards
HFET	29,244/47,054	1.78	0.16	1.19	1 Retard - 55 mph cruise
CVS-CH	29,310/47,160	12.44	0.71	1.62	(6K) No retards
HFET	29,321/47,178	2.01	0.20	1.36	1 Retard - 55 mph cruise
CVS-CH	31,223/50,238	3.78	0.55	1.52	(8K) Idle CO leaned, carburetor cleaned, No retards
HFET	31,234/50,256	1.40	0.21	1.65	
CVS-CH	31,245/50,273	5.67	0.57	1.47	(8K) No retards
HFET	31,256/50,291	1.61	0.22	1.29	No retards
CVS-CH	33,494/53,892	6.46	1.33	1.73	(10K) No retards - 2 stalls
HFET	33,505/53,910	2.38	0.31	1.51	No retards
CVS-CH	33,516/53,927	6.99	0.89	1.73	(10K) No retards
HFET	33,527/53,945	2.26	0.34	1.57	No retards
CVS-CH	35,159/56,571	5.03	0.66	2.09	(12K) New spark plugs, No retards
HFET	35,170/56,589	2.37	0.28	1.65	
CVS-CH	35,180/56,605	5.10	0.75	1.96	(12K) No retards
HFET	35,191/56,623	2.54	0.30	1.50	

APPENDIX B-11

Cycle	Miles	CO	HC	NO_x	Remarks
CVS-CH	35,341	4.27	0.63	1.96	12 K - No retards
HFET	35,352	2.23	0.24	1.56	12 K - No retards
CVS-CH	35,963	6.39	0.54	2.06	CX-82 - No retards
HFET	35,974	2.35	0.22	1.70	CX-82 - No retards
CVS-CH	35,985	7.85	0.43	1.66	CX-82 - Lots of retard
HFET	35,996	2.02	0.15	1.33	CX-82 - Accelerometer Malfunction
CVS-CH	36,244	5.32	0.53	1.87	C-82 - No retards
HFET	36,255	3.35	0.53	1.46	C-82 - No retards
CVS-CH	36,285	5.19	0.57	1.81	C-82 - No retards
HFET	36,296	3.24	0.26	1.46	Delay 128, Delay - 4,100 mV threshold
CVS-CH	40,667	12.06	0.80	1.82	4 K AMA Cycle
HFET	40,678	5.48	0.34	1.46	No retards; 128 X 4 Delay, 100 mV threshold
CVS-CH	40,829	6.76	0.69	1.56	No retards; 128 X 4 Delay, 100 mV threshold
HFET	40,840	4.92	0.40	1.41	No retards; 128 X 4 Delay, 100 mV threshold
CVS-CH	40,872	6.34	0.64	1.64	No retards; 128 X 4 Delay, 100 mV threshold
HFET	40,883	4.79	0.30	1.35	No retards; 128 X 4 Delay, 100 mV threshold
CVS-CH	40,910	5.95	0.73	2.39	CX-86 - 12° BTC Timing
HFET	40,921	5.53	0.37	2.08	128 X 4 Delay, 100 mV threshold No retards
CVS-CH	40,957	10.43	1.02	2.51	128 X 4 Delay, 100 mV threshold No retards
HFET	40,968	4.95	0.64	2.39	128 X 4 Delay, 100 mV threshold No retards

APPENDIX B-12

FUEL ECONOMY OF 1975 NOVA

Test Cycle	Mileage (miles/km)	Fuel Economy - MPG/km per litre	
		From Emissions	From Weight
CVS-CH	564/907	12.12/5.15	12.72/5.41
EPA-H	575/925	17.24/7.33	17.56/7.46
CVS-CH	585/941	11.58/4.92	12.01/5.11
EPA-H	596/959	16.36/6.95	16.35/6.95
CVS-CH	606/975	11.81/5.02	12.36/5.25
EPA-H	617/993	16.40/6.97	17.23/7.32
CVS-CH	6860/11,040	12.00/5.10	12.30/5.23
EPA-H	6871/11,058	16.27/6.92	15.27/6.49
CVS-CH	6882/11,076	12.19/15.19	12.13/5.16
EPA-H	6893/11,093	16.39/6.97	15.56/6.61
CVS-CH	8903/14,328	11.11/4.73	11.14/4.74
EPA-H	8915/14,347	15.49/6.59	14.91/6.34
CVS-CH	8925/14,363	11.62/4.94	11.91/5.06
EPA-H	8936/14,381	15.87/6.75	15.16/6.44
CVS-CH	11,025/17,743	12.55/5.34	12.11/5.15
EPA-H	11,036/17,761	18.63/7.92	15.95/6.78
CVS-CH	11,046/17,777	12.72/5.41	12.15/5.17
EPA-H	11,058/17,796	19.71/8.38	16.35/6.95
CVS-CH	13,148/21,160	11.94/5.08	12.24/5.20
EPA-H	13,159/21,177	15.95/6.78	15.75/6.70
CVS-CH	13,170/21,195	11.95/5.08	12.58/5.35
EPA-H	13,181/21,213	16.74/7.12	16.11/6.85
CVS-CH	13,191/21,229	11.93/5.07	12.45/5.29
EPA-H	13,202/21,247	16.39/6.97	16.03/6.81

APPENDIX B-13

	Fuel Economy - mpg/kmpL					
	CVS - CH			Fuel Economy Cycle		
Miles/km	Emissions	Weight	Flowmeter	Emissions	Weight	Flowmeter
13,947/22,441	11.10/4.72	11.32/4.81	-	16.11/6.85	16.90/7.18	-
13,968/22,475	11.17/4.75	11.38/4.84	-	15.91/6.76	16.71/7.10	-
13,994/22,516	11.56/4.91	11.95/5.08	-	16.31/6.93	16.52/7.02	-
14,015/22,550	10.89/4.63	11.18/4.75	-	16.48/7.01	17.00/7.23	-
14,048/22,603	11.19/4.76	11.42/4.85	-	15.87/6.75	16.66/7.08	-
14,072/22,642	11.59/4.93	11.34/4.82	11.26/4.79	16.52/7.02	16.33/6.94	16.03/6.81
14,094/22,677	11.88/5.05	11.54/4.91	11.43/4.86	17.32/7.36	16.33/6.94	16.14/6.86
14,234/22,902	12.66/5.38	11.88/5.05	11.69/4.97	19.18/8.15	17.51/7.44	17.13/7.28
14,257/22,940	12.14/5.16	11.73/4.99	11.64/4.95	17.75/7.55	17.20/7.31	16.97/7.21
14,280/22,977	12.51/5.32	11.95/5.08	11.84/5.03	17.90/7.61	17.25/7.33	17.03/7.24
14,457/23,261	11.78/5.01	11.86/5.04	11.71/4.98	17.46/7.42	17.15/7.29	16.87/7.17

APPENDIX B-14

Test No.	Mileage Miles/km	Fuel Economy - mpg/kmpl					
		CVS-CH			Highway Fuel Economy		
		Emissions	Weight	Flowmeter	Emissions	Weight	Flowmeter
	Averages:						
	8:1 C.R.	11.34/4.82	11.45/4.87	-	16.36/6.96	16.64/7.07	-
	9:1 C.R.	12.27/5.22	11.86/5.04	11.72/4.98	18.07/7.68	17.28/7.35	17.00/7.23
1	14,480/23,303	11.95/5.08	12.61/5.36	12.46/5.30	17.90/7.61	17.46/7.42	17.12/7.28
2	14,503/23,340	12.47/5.30	12.56/5.34	12.41/5.28	17.70/7.52	17.46/7.42	17.25/7.33
3	14,525/23,375	12.35/5.25	12.61/5.36	12.47/5.30	17.46/7.42	17.67/7.51	17.43/7.41
	Average:						
	Tests 1 to 3	12.26/5.21	12.59/5.35	12.45/5.29	17.69/7.52	17.53/7.45	17.27/7.34
4	14,549/23,414	13.17/5.60	12.88/5.48	12.79/5.44	17.70/7.52	17.56/7.46	17.35/7.38
5	14,572/23,451	13.12/5.58	12.99/5.52	13.05/5.55	18.57/7.89	18.33/7.79	18.08/7.69
6	14,640/23,560	13.04/5.54	12.61/5.36	12.42/5.28	17.66/7.51	17.35/7.38	17.12/7.28
7	14,842/23,885	13.25/5.63	12.91/5.49	12.87/5.47	18.36/7.80	17.78/7.56	17.55/7.46
8	15,141/24,366	12.53/5.33	11.97/5.09	11.87/5.05	17.80/7.57	17.51/7.44	17.23/7.32
	Average:						
	Tests 6 to 8	12.94/5.50	12.50/5.31	12.39/5.27	17.94/7.63	17.55/7.46	17.30/7.35

APPENDIX B-15

Mileage (miles/km)	Fuel Economy (mpg/kmpg)					
	CVS-CH			HFET		
	Emissions	Weight	Flowmeter	Emissions	Weight	Flowmeter
16,549/26,627	11.83/5.03	11.30/4.80	11.24/4.78	18.57/7.89	16.42/6.98	15.98/7.27
16,576/26,671	11.78/5.01	11.75/4.99	11.70/4.97	19.90/8.46	17.56/7.46	17.30/7.35

APPENDIX B-16

Mileage (miles/km)	Fuel Economy (mpg/kmpl)					
	CVS-CH			HFET		
	Emissions	Weight	Flowmeter	Emissions	Weight	Flowmeter
16,784/27,005	12.75/5.42	11.95/5.09	11.77/5.00	20.21/8.59	18.28/7.77	17.90/7.61
16,824/27,070	12.25/5.21	12.34/5.24	12.15/5.16	20.47/8.70	18.05/7.67	17.87/7.59
18,283/29.417	12.56/5.34	12.23/5.20	----	17.66/7.50	17.83/7.58	----
18,304/29,451	13.20/5.61	12.88/5.47	---	19.24/8.18	18.63/7.92	----

APPENDIX B-17

		Fuel Economy (mpg/kmpl)					
		CVS-CH			HFET		
Test	Miles/km	Emissions	Weight	Flowmeter	Emissions	Weight	Flowmeter
1	18,328/29,490	12.68/5.39	11.56/4.91	11.75/4.99	18.36/7.80	16.80/7.14	16.82/7.15
2	18,357/29,536	12.16/5.17	13.33/5.67	11.48/4.88	18.47/7.85	20.24/8.60	18.18/7.73
3	18,378/29,570	10.89/4.63	10.37/4.41	10.50/4.46	17.61/7.48	16.11/6.85	16.18/6.88
4	18,449/29,684	12.17/5.17	11.40/4.85	11.58/4.92	17.80/7.57	17.00/7.23	17.03/7.24
5	18,475/29,726	11.61/4.93	11.62/4.94	11.79/5.01	18.21/7.74	17.25/7.33	17.12/17.28
6	18,581/29,897	12.31/5.23	11.58/4.92	11.73/4.99	19.84/8.18	17.83/7.58	17.79/7.56
7	18,665/30,032	11.97/5.09	12.13/5.16	12.29/5.22	18.47/7.85	18.16/7.72	18.20/7.74
8	18,723/30,125	12.33/5.24	11.97/5.09	12.15/5.16	19.13/8.13	17.72/7.53	17.83/7.58
	5-8 Average (9:1)	12.06/5.13	11.83/5.03	11.99/5.10	18.91/8.04	17.74/7.54	17.74/7.54
	Average (8:1)	11.34/4.82	11.45/4.87	11.35/4.82	16.36/6.95	16.44/6.99	16.09/6.84
	% Improvement	6.3	3.3	5.6	15.6	7.9	10.3

APPENDIX B-18

	Fuel Economy (mpg/kmpl)					
	CVS-CH			HFET		
Miles/km	Emissions	Weight	Flowmeter	Emissions	Weight	Flowmeter
18,774/30,207	12.45/5.29	11.93/5.07	12.05/5.12	19.24/8.18	17.83/7.58	17.90/7.61
19,689/31,680	12.11/5.15	11.56/4.91	11.49/4.88	18.05/7.67	17.35/7.37	17.22/7.32

APPENDIX B-19

	Fuel Economy (mpg/kmph)					
	CVS - CH			HFET		
Miles/km	Emissions	Weight	Flowmeter	Emissions	Weight	Flowmeter
21,638/34,816	11.18/4.75	11.44/4.86	11.38/4.84	17.61/7.48	16.95/7.20	16.89/7.18
21,765/35,020	11.07/4.70	10.86/4.62	11.00/4.68	16.65/7.08	16.02/6.81	16.13/6.86
21,803/35,081	11.21/4.76	11.44/4.86	11.71/4.98	17.75/7.54	16.56/7.04	16.70.7.10
21,886/35,215	12.11/5.15	12.15/5.16	12.29/5.22	17.85/7.59	17.46/7.42	17.42/7.4
21,947/35,313	11.40/4.85	11.62/4.94	11.79/5.01	17.14/7.28	16.82/7.15	16.11/6.85
21,976/35,359	10.91/4.64	11.39/4.84	12.03/5.11	17.18/7.30	16.85/7.16	16.75/7.12
22,039/35,461	11.28/4.79	11.42/4.85	11.58/4.92	17.46/7.42	16.90/7.18	16.97/7.21
22,088/35,540	11.29/4.80	11.67/4.96	11.83/5.03	18.05/7.67	16.84/7.16	16.77/7.13

APPENDIX B-20

	Fuel Economy (mpg/kmpl)					
	CVS-CH			HFET		
Miles/km	Emissions	Weight	Flowmeter	Emissions	Weight	Flowmeter
22,141/35,625	11.79/5.01	11.73/4.99	11.87/5.05	17.56/7.46	17.25/7.33	17.21/7.31
22,435/36,098	11.32/4.81	11.22/4.77	11.33/4.82	17.51/7.44	16.71/7.10	16.62/7.06
22,459/36,137	10.98/4.67	11.24/4.78	11.06/4.70	17.90/7.61	16.85/7.16	17.09/7.26
22,613/36,384	11.51/4.89	11.60.4.93	11.76/5.00	18.47/7.85	17.05/7.25	17.12/7.28
Average	11.40/4.85	11.45/4.87	11.51/4.89	17.86/7.59	16.97/7.21	17.01/7.23

APPENDIX B-21

	Fuel Economy (mpg/kmpl)					
	CVS-CH			HFET		
Miles/km	Emissions	Weight	Flowmeter	Emissions	Weight	Flowmeter
(6K) 29,233/47,036	11.25/4.78	11.01/4.68	---	17.28/7.34	16.02/6.81	16.23/6.90
(6K) 29,310/46,160	10.50/4.46	10.99/4.67	11.07/4.70	16.35/6.95	15.93/6.77	15.92/6.77
(8K) 31,223/50,238	11.67/4.96	11.84/5.03	11.88/5.05	17.70/7.52	16.42/6.98	16.42/6.98
(8K) 31,245/50,273	11.45/4.87	11.44/4.86	11.50/4.89	17.51/7.44	16.11/6.85	16.16/6.87
(10K) 33,494/53,892	10.98/4.67	10.99/4.67	11.10/4.72	17.66/7.51	16.56/7.04	16.78/7.13
(10K) 33,516/53,927	11.26/4.79	11.50/4.89	11.54/4.90	17.56/7.46	16.47/7.00	16.52/7.02
(12K) 35,159/56,571	12.07/5.13	11.82/5.02	11.90/5.06	18.10/7.69	16.71/7.10	16.79/7.14
(12K) 35,180/56,605	11.40/4.85	11.42/4.85	11.44/4.86	17.75/7.54	16.52/7.02	16.57/7.04

APPENDIX B-22

Fuel Economy (mpg/kmpℓ)

Miles	CVS-CH Emissions	CVS-CH Weight	CVS-CH Flowmeter	HFET Emissions	HFET Weight	HFET Flowmeter
(12 K)35,341	11.94/5.07	11.95/5.08	12.03/5.11	17.66/7.51	17.20/7.31	17.30/7.35
35,963	12.20/5.19	11.42/4.85	11.81/5.02	18.04/7.67	16.90/7.18	17.37/7.38
35,985	11.54/4.90	10.86/4.61	11.17/4.75	17.54/7.45	15.97/6.79	16.39/6.97
36,244	13.26/5.64	11.19/4.76	11.30/4.80	20.17/8.57	16.67/7.08	16.85/7.16
36,285	11.89/5.05	11.56/4.91	11.66/4.96	18.40/7.82	16.87/7.17	16.72/7.11
(4 K AMA)40,667	12.12/5.15	11.22/4.77	11.36/4.83	19.22/8.17	16.71/7.10	16.77/7.13
(4 K AMA)40,829	11.88/5.05	11.52/4.90	11.64/4.95	18.40/7.82	16.71/7.10	16.73/7.11
(4 K AMA)40,872	12.06/5.13	11.32/4.81	11.45/4.87	18.67/7.93	16.71/7.10	16.72/7.11
40,910	13.05/5.55	12.42/5.28	12.41/5.27	18.83/8.00	17.38/7.39	17.12/7.28
40,957	12.75/5.42	12.23/5.20	12.18/5.18	18.48/7.85	17.23/7.32	--

```
DATE 7-9-75                          VEHICLE NO. 26                  MAKE NOVA
STAND 3                              ODOMETER 564
FUEL  INDOLENE


WET BULB TEMP     80                 ABSOLUTE HUMIDITY  140.0 GRNS/LBS DRY AIR
DRY BULB TEMP     89                 RELATIVE HUMIDITY   67.0 PCT
BAROMETRIC PRES. 754.                PUMP INLET PRES.    20.80 INCHES OF H2O


                             MEASURED CONCENTRATIONS
 BAG             1       AIR(1)       2        AIR(2)       3        AIR(3)

CO,PPM       442.50       1.00       3.00       1.00      17.00       2.00
HC,PPM C6     14.20       1.60       3.00       1.70       5.60       1.86
NOX,PPM       47.50       0.48      16.00       0.68      45.50       0.41
CO2,PCT        1.44       0.04       1.00       0.04       1.35       0.05

PUMP REV     13392.                22972.                13392.
TEMP              130. F
PUMP CAPACITY     0.3115 CF/REV



                        RESULTS
BAG             1              2              3

VMIX         3517.          6033.          3517.
DF             8.95          13.30           9.88

               MASS EMISSIONS, GRAMS/BAG

CO           48.67           0.39           1.67
HC            4.40           0.84           1.35
NOX           8.96           5.02           8.59
CO2        2570.46        3028.22        2380.05
CARBON      726.14         827.28         651.38

FUEL
LBS/BAG        1.84           2.10           1.65

                                        INDOLENE MILEAGE
AVERAGE COLD START MILEAGE          11.73 MILES/GAL        4.989 KM/LITRE
AVERAGE HOT START MILEAGE           12.33                  5.242
OVERALL TEST MILEAGE                12.12 12.72            5.156
WEIGHTED TEST MILEAGE               12.06                  5.130


                       WEIGHTED MASS EMISSIONS

              CO         2.970 G/MILE          1.845 G/KM
              HC         0.467                 0.290
              NOX        1.837                 1.141
    CORRECTED NOX        2.645                 1.643
              CO2      732.020               454.856
```

```
DATE 7-10-75                 VEHICLE NO. 26              MAKE NOVA
STAND 3                      ODOMETER 585
FUEL  INDOLENE

WET BULB TEMP     77         ABSOLUTE HUMIDITY  133.0 GRNS/LBS DRY AIR
DRY BULB TEMP     82         RELATIVE HUMIDITY   79.0 PCT
BAROMETRIC PRES. 755.        PUMP INLET PRES.    20.90 INCHES OF H2O

                        MEASURED CONCENTRATIONS
 BAG             1       AIR(1)      2       AIR(2)      3       AIR(3)

CO,PPM      592.50       7.00      8.75      8.00      3.00      3.00
HC,PPM C6    22.00       2.04      2.90      1.92      3.70      1.74
NOX,PPM      41.50       0.20     15.00      0.43     45.00      0.45
CO2,PCT       1.57       0.05      1.03      0.04      1.37      0.04
SO2,PPM       1.00                 0.50                0.00

PUMP REV    13435.             22885.             13435.
TEMP             130. F
PUMP CAPACITY     0.3115 CF/REV


                 RESULTS
BAG            1            2            3

VMIX       3532.        6017.        3532.
DF           8.15        12.97         9.72

            MASS EMISSIONS, GRAMS/BAG

CO          64.45         0.22         0.02
HC           6.99         0.66         0.74
NOX          7.90         4.75         8.53
CO2       2804.50      3081.14      2442.92
CARBON     799.02       841.49       667.30
SO2          0.27         0.23         0.00

FUEL
LBS/BAG      2.03         2.14         1.69

                                       INDOLENE MILEAGE
AVERAGE COLD START MILEAGE      11.11 MILES/GAL       4.724 KM/LITRE
AVERAGE HOT START MILEAGE       12.08                 5.137
OVERALL TEST MILEAGE            11.58 12.21           4.926
WEIGHTED TEST MILEAGE           11.64                 4.951


                    WEIGHTED MASS EMISSIONS

            CO        3.728 G/MILE        2.316 G/KM
            HC        0.545               0.339
            NOX       1.736               1.078
  CORRECTED NOX       2.387               1.483
            CO2     757.273             470.547
            SO2       0.046               0.029
            SO2       0.045               0.028   UNWEIGHTED
```

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                                                                  MAKE NOVA
DATE 7-11-75                      VEHICLE NO. 26
STAND 3                           ODOMETER 606.4
FUEL INDOLENE

WET BULB TEMP     75              ABSOLUTE HUMIDITY  119.0 GRNS/LBS DRY AIR
DRY BULB TEMP     83              RELATIVE HUMIDITY   69.0 PCT
BAROMETRIC PRES. 755.             PUMP INLET PRES.    21.00 INCHES OF H2O

                             MEASURED CONCENTRATIONS
 BAG              1        AIR(1)      2       AIR(2)      3       AIR(3)

CO,PPM        680.00       3.00      8.00      6.00     10.20      3.00
HC,PPM C6      30.00       1.30      2.20      1.36      3.00      1.02
NOX,PPM        37.00       0.22     15.80      0.17     51.00      0.10
CO2,PCT         1.50       0.05      1.00      0.04      1.37      0.03
SO2,PPM         2.00                 1.00                1.00

PUMP REV    13468.                 22874.              13446.
TEMP            130. F
PUMP CAPACITY     0.3115 CF/REV


                          RESULTS
BAG             1             2              3

VMIX         3539.         6011.          3533.
DF            8.46         13.30           9.72

                MASS EMISSIONS, GRAMS/BAG

CO           74.98          0.44           0.82
HC           10.00          0.55           0.72
NOX           7.05          5.09           9.74
CO2        2671.81       3009.90        2455.11
CARBON      769.94        822.05         670.96
SO2           0.54          0.46           0.27

FUEL
LBS/BAG       1.95          2.09           1.70

                                     INDOLENE MILEAGE
AVERAGE COLD START MILEAGE        11.45 MILES/GAL        4.868 KM/LITRE
AVERAGE HOT START MILEAGE         12.21                  5.191
OVERALL TEST MILEAGE              11.81                  5.023
WEIGHTED TEST MILEAGE             11.87                  5.047


                       WEIGHTED MASS EMISSIONS

              CO          4.421 G/MILE           2.747 G/KM
              HC          0.702                  0.436
              NOX         1.824                  1.133
    CORRECTED NOX         2.299                  1.428
              CO2       741.092                460.493
              SO2         0.114                  0.070
              SO2         0.116                  0.072     UNWEIGHTED
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DATE 8-19-75                   VEHICLE NO. 26                 MAKE NOVA
STAND 3                        ODOMETER 6860.25
FUEL INDOLENE

WET BULB TEMP     68           ABSOLUTE HUMIDITY   80.0 GRNS/LBS DRY AIR
DRY BULB TEMP     82           RELATIVE HUMIDITY   48.0 PCT
BAROMETRIC PRES. 764.          PUMP INLET PRES.    20.60 INCHES OF H2O

                           MEASURED CONCENTRATIONS
 BAG             1       AIR(1)      2       AIR(2)       3       AIR(3)

CO,PPM       485.00       3.00      8.00      3.00      28.00      3.00
HC,PPM C6     13.00       1.60      2.80      1.60       4.00      1.30
NOX,PPM       46.50       0.22     15.50      0.09      36.50      0.40
CO2,PCT        1.41       0.05      1.03      0.04       1.31      0.04
SO2,PPM        1.00                 0.50                 1.50

PUMP REV     13435.               22961.               13446.
TEMP             130. F
PUMP CAPACITY     0.3115 CF/REV


                       RESULTS
BAG             1           2           3

VMIX         3575.       6110.       3578.
DF             9.13       12.97       10.12

                 MASS EMISSIONS, GRAMS/BAG

CO           54.41        1.00        2.85
HC            4.05        0.79        0.99
NOX           8.96        5.10        7.00
CO2        2534.98     3140.42     2375.05
CARBON      718.62      858.11      650.21
SO2           0.27        0.23        0.41

FUEL
LBS/BAG      1.82        2.18        1.65

                                  INDOLENE MILEAGE
AVERAGE COLD START MILEAGE      11.56 MILES/GAL       4.915 KM/LITRE
AVERAGE HOT START MILEAGE       12.08                 5.138
OVERALL TEST MILEAGE            12.00  12.30          5.104
WEIGHTED TEST MILEAGE           11.85                 5.040


                        WEIGHTED MASS EMISSIONS

                CO       3.471 G/MILE       2.156 G/KM
                HC       0.413              0.256
                NOX      1.726              1.072
      CORRECTED NOX      1.768              1.098
                CO2    744.566            462.651
                SO2      0.078              0.049
                SO2      0.084              0.052   UNWEIGHTED
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DATE 8-20-75                  VEHICLE NO. 26                 MAKE NOVA
STAND 3                       ODOMETER 6881.6
FUEL INDOLENE

WET BULB TEMP     67          ABSOLUTE HUMIDITY   78.0 GRNS/LBS DRY AIR
DRY BULB TEMP     80          RELATIVE HUMIDITY   51.0 PCT
BAROMETRIC PRES. 766.         PUMP INLET PRES.    20.80 INCHES OF H20

                         MEASURED CONCENTRATIONS
 BAG             1        AIR(1)     2       AIR(2)      3       AIR(3)

CO,PPM        603.00       3.00     3.00      2.00     18.80      1.00
HC,PPM C6      12.60       1.12     2.20      1.10      3.60      1.38
NOX,PPM        52.50       0.25    16.10      0.25     36.00      0.47
CO2,PCT         1.41       0.04     0.97      0.04      1.31      0.04
SO2,PPM         1.00                0.50                1.00

PUMP REV     13489.              22885.             13468.
TEMP             130. F
PUMP CAPACITY      0.3115 CF/REV


                       RESULTS
BAG            1           2           3

VMIX        3597.        6103.       3592.
DF            9.07        13.72       10.13

                MASS EMISSIONS, GRAMS/BAG

CO           68.09         0.21        2.02
HC            4.09         0.70        0.82
NOX          10.18         5.24        6.92
CO2        2557.59      2962.42     2384.26
CARBON      730.68       809.12      652.23
SO2           0.27         0.23        0.27

FUEL
LBS/BAG       1.85         2.05        1.65

                                   INDOLENE MILEAGE
AVERAGE COLD START MILEAGE       11.84 MILES/GAL       5.033 KM/LITRE
AVERAGE HOT START MILEAGE        12.47                 5.304
OVERALL TEST MILEAGE             12.19 12.13           5.186
WEIGHTED TEST MILEAGE            12.19                 5.184


                      WEIGHTED MASS EMISSIONS

                 CO        4.086 G/MILE          2.539 G/KM
                 HC        0.391                 0.243
                 NOX       1.809                 1.124
       CORRECTED NOX       1.835                 1.140
                 CO2     722.829               449.145
                 SO2       0.068                 0.042
                 SO2       0.071                 0.044   UNWEIGHTED
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DATE 8-25-75                      VEHICLE NO. 26                  MAKE NOVA
STAND 3                           ODOMETER 8903
FUEL INDOLENE

WET BULB TEMP     79              ABSOLUTE HUMIDITY  140.0 GRNS/LBS DRY AIR
DRY BULB TEMP     85              RELATIVE HUMIDITY   76.5 PCT
BAROMETRIC PRES. 761.             PUMP INLET PRES.    20.80 INCHES OF H2O

                              MEASURED CONCENTRATIONS
 BAG             1       AIR(1)      2       AIR(2)      3       AIR(3)

CO,PPM       637.00       4.50      8.00      3.00     20.50      3.00
HC,PPM C6     17.60       2.20      3.20      1.90      4.00      1.80
NOX,PPM       39.50       0.30     11.00      0.33     24.00      0.30
CO2,PCT        1.51       0.05      1.12      0.04      1.41      0.05
SO2,PPM        1.00                 0.20                0.80

PUMP REV    13543.                22928.              13435.
TEMP             130. F
PUMP CAPACITY     0.3115 CF/REV


                          RESULTS
BAG            1            2            3

VMIX        3587.        6073.        3558.
DF             8.42        11.93         9.41

                  MASS EMISSIONS, GRAMS/BAG

CO            70.81         0.99         1.97
HC             5.50         0.86         0.83
NOX            7.62         3.51         4.57
CO2         2743.36      3394.08      2535.82
CARBON       783.77       927.39       693.57
SO2            0.27         0.09         0.22

FUEL
LBS/BAG        1.99         2.35         1.76

                                      INDOLENE MILEAGE
AVERAGE COLD START MILEAGE        10.65 MILES/GAL       4.529 KM/LITRE
AVERAGE HOT START MILEAGE         11.24                 4.781
OVERALL TEST MILEAGE              11.11  11.14          4.727
WEIGHTED TEST MILEAGE             10.98                 4.670


                       WEIGHTED MASS EMISSIONS

                CO       4.342 G/MILE        2.698 G/KM
                HC       0.494               0.307
                NOX      1.253               0.779
      CORRECTED NOX      1.805               1.121
                CO2    802.552             498.682
                SO2      0.045               0.028
                SO2      0.053               0.033   UNWEIGHTED
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DATE 8-26-75                    VEHICLE NO. 26               MAKE NOVA
STAND 3                         ODOMETER 8925
FUEL INDOLENE

WET BULB TEMP     77            ABSOLUTE HUMIDITY  136.0 GRNS/LBS DRY AIR
DRY BULB TEMP     80            RELATIVE HUMIDITY   88.0 PCT
BAROMETRIC PRES. 763.           PUMP INLET PRES.    20.60 INCHES OF H2O

                         MEASURED CONCENTRATIONS
 BAG             1      AIR(1)     2      AIR(2)      3      AIR(3)

CO,PPM      754.00      7.00     10.20      8.00     21.80      6.00
HC,PPM C6    15.80      2.60      3.40      2.40      4.40      2.10
NOX,PPM      33.20      0.62     11.20      0.85     23.00      0.92
CO2,PCT       1.47      0.05      1.03      0.05      1.41      0.04
SO2,PPM       1.50                0.50                1.00

PUMP REV    13414.             22928.              13424.
TEMP            130. F
PUMP CAPACITY    0.3115 CF/REV


                    RESULTS
BAG            1            2            3

VMIX       3567.        6098.        3570.
DF           8.61        12.97         9.45

               MASS EMISSIONS, GRAMS/BAG

CO          82.94         0.50         1.80
HC           4.71         0.70         0.88
NOX          6.30         3.43         4.28
CO2       2638.61      3096.25      2537.79
CARBON     759.71       845.77       694.08
SO2          0.41         0.23         0.27

FUEL
LBS/BAG     1.93         2.15         1.76

                                     INDOLENE MILEAGE
AVERAGE COLD START MILEAGE        11.35 MILES/GAL      4.827 KM/LITRE
AVERAGE HOT START MILEAGE         11.84                5.033
OVERALL TEST MILEAGE              11.62  11.91 MPG     4.943
WEIGHTED TEST MILEAGE             11.62                4.943


                        WEIGHTED MASS EMISSIONS

              CO      4.960 G/MILE         3.082 G/KM
              HC      0.432                0.268
              NOX     1.146                0.712
    CORRECTED NOX     1.607                0.998
              CO2   756.986              470.369
              SO2     0.076                0.047
              SO2     0.084                0.052   UNWEIGHTED
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DATE 9-3-75                            VEHICLE NO. 26              MAKE NOVA
STAND 3                                ODOMETER 11024.9
FUEL INDOLENE

WET BULB TEMP     61                   ABSOLUTE HUMIDITY   66.0 GRNS/LBS DRY AIR
DRY BULB TEMP     70                   RELATIVE HUMIDITY   60.0 PCT
BAROMETRIC PRES. 760.                  PUMP INLET PRES.    20.80 INCHES OF H2O

                                  MEASURED CONCENTRATIONS
 BAG                1        AIR(1)      2        AIR(2)       3        AIR(3)

CO,PPM         902.50        6.00      6.00        2.00      39.50       1.00
HC,PPM C6       16.80        1.10      2.30        1.10       3.60       1.10
NOX,PPM         67.00        0.72     22.00        0.48      52.00       0.40
CO2,PCT          1.35        0.05      0.98        0.04       1.26       0.04
SO2,PPM          3.00                  1.20                   2.00

PUMP REV    13360.                   22864.                 13500.
TEMP            130. F
PUMP CAPACITY    0.3115 CF/REV


                         RESULTS
BAG             1            2            3

VMIX         3533.        6047.        3570.
DF            9.26        13.64        10.58

              MASS EMISSIONS, GRAMS/BAG

CO           99.77         0.78         4.34
HC            5.47         0.75         0.91
NOX          12.70         7.06         9.98
CO2        2391.90      2956.83      2265.84
CARBON      700.25       807.89       620.98
SO2           0.81         0.56         0.55

FUEL
LBS/BAG      1.78         2.05         1.57

                                      INDOLENE MILEAGE
AVERAGE COLD START MILEAGE        12.08 MILES/GAL        5.139 KM/LITRE
AVERAGE HOT START MILEAGE         12.75                  5.424
OVERALL TEST MILEAGE              12.55  12.11           5.339
WEIGHTED TEST MILEAGE             12.46                  5.298


                      WEIGHTED MASS EMISSIONS

               CO        6.155 G/MILE        3.824 G/KM
               HC        0.484               0.301
               NOX       2.428               1.509
     CORRECTED NOX       2.329               1.447
               CO2     703.584             437.186
               SO2       0.163               0.101
               SO2       0.175               0.109   UNWEIGHTED
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DATE 9-4-75                  VEHICLE NO. 26               MAKE NOVA
STAND 3                      ODOMETER 11046.45
FUEL INDOLENE

WET BULB TEMP    65          ABSOLUTE HUMIDITY   81.0 GRNS/LBS DRY AIR
DRY BULB TEMP    72          RELATIVE HUMIDITY   68.0 PCT
BAROMETRIC PRES. 762.        PUMP INLET PRES.    20.50 INCHES OF H2O

                        MEASURED CONCENTRATIONS
 BAG           1      AIR(1)     2     AIR(2)     3      AIR(3)

CO,PPM      718.00     7.00     8.00     3.00    32.00     3.00
HC,PPM C6    15.00     1.60     3.40     1.70     4.00     1.40
NOX,PPM      52.00     0.35    17.30     0.33    44.00     0.52
CO2,PCT       1.32     0.04     0.98     0.04     1.23     0.05
SO2,PPM       2.00              1.50              1.50

PUMP REV    13446.            22907.            13478.
TEMP           130. F
PUMP CAPACITY    0.3116 CF/REV


                   RESULTS
BAG         1           2           3

VMIX      3570.       6082.       3578.
DF         9.58       13.63       10.84

           MASS EMISSIONS, GRAMS/BAG

CO        79.79        0.99        3.28
HC         4.74        1.08        0.95
NOX        9.99        5.59        8.43
CO2     2377.32     2973.87     2198.23
CARBON   687.08      812.91      602.12
SO2        0.55        0.70        0.41

FUEL
LBS/BAG     1.74        2.06        1.53

                                   INDOLENE MILEAGE
AVERAGE COLD START MILEAGE      12.15 MILES/GAL     5.167 KM/LITRE
AVERAGE HOT START MILEAGE       12.88               5.477
OVERALL TEST MILEAGE            12.72 12.15         5.408
WEIGHTED TEST MILEAGE           12.56               5.339


                    WEIGHTED MASS EMISSIONS

            CO       4.957 G/MILE       3.080 G/KM
            HC       0.489              0.304
            NOX      1.960              1.218
  CORRECTED NOX      2.017              1.253
            CO2    699.881            434.886
            SO2      0.157              0.097
            SO2      0.152              0.094   UNWEIGHTED
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DATE 9/8/75                          VEHICLE NO. 7526              MAKE NOVA
STAND 3                              ODOMETER 13,148.0
FUEL INDOLENE

WET BULB TEMP      78                ABSOLUTE HUMIDITY  134.0 GRNS/LBS DRY AIR
DRY BULB TEMP      85                RELATIVE HUMIDITY   73.0 PCT
BAROMETRIC PRES. 765.                PUMP INLET PRES.    23.10 INCHES OF H2O

                              MEASURED CONCENTRATIONS
BAG               1       AIR(1)     2       AIR(2)      3       AIR(3)

CO,PPM         648.00      3.00     6.00      2.00     13.00      2.00
HC,PPM C6       16.80      2.30     3.60      2.20      4.80      2.20
NOX,PPM         43.00      0.50    14.70      0.40     35.50      0.40
CO2,PCT          1.48      0.05     1.00      0.05      1.35      0.05
SO2,PPM          1.50               0.00                0.50

PUMP REV     13446.               22961.               13424.
TEMP             130. F
PUMP CAPACITY     0.3115 CF/REV


                          RESULTS
BAG              1            2           3

VMIX          3560.         6079.       3554.
DF               8.63         13.36        9.89

              MASS EMISSIONS, GRAMS/BAG

CO              71.79          0.78        1.24
HC               5.15          0.93        0.98
NOX              8.20          4.71        6.76
CO2           2650.33       3006.34     2405.06
CARBON         758.50        821.55      657.70
SO2              0.41          0.00        0.13

FUEL
LBS/BAG          1.92          2.08        1.67

                                           INDOLENE MILEAGE
AVERAGE COLD START MILEAGE            11.53 MILES/GAL         4.905 KM/LITRE
AVERAGE HOT START MILEAGE             12.32                   5.239
OVERALL TEST MILEAGE                  11.94 12.24             5.080
WEIGHTED TEST MILEAGE                 11.97                   5.090


                          WEIGHTED MASS EMISSIONS

                CO          4.315 G/MILE        2.681 G/KM
                HC          0.494               0.307
                NOX         1.613               1.002
      CORRECTED NOX         2.232               1.387
                CO2       735.583             457.070
                SO2         0.034               0.021
                SO2         0.050               0.031   UNWEIGHTED
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DATE 9/9/75                   VEHICLE NO. 26                 MAKE NOVA
STAND 3                       ODOMETER 13,169.6
FUEL INDOLENE

WET BULB TEMP     63          ABSOLUTE HUMIDITY   67.0 GRNS/LBS DRY AIR
DRY BULB TEMP     75          RELATIVE HUMIDITY   52.0 PCT
BAROMETRIC PRES. 768.         PUMP INLET PRES.    20.60 INCHES OF H2O

                           MEASURED CONCENTRATIONS
 BAG             1       AIR(1)      2       AIR(2)      3       AIR(3)

CO,PPM       592.00      3.00       4.50      1.00     45.00      2.00
HC,PPM C6     12.40      1.40       2.50      1.04      4.20      1.08
NOX,PPM       61.50      0.37      19.80      0.32     48.00      0.35
CO2,PCT        1.41      0.04       1.00      0.04      1.32      0.04
SO2,PPM        1.00                 0.50                0.00

PUMP REV     13576.               22961.              13489.
TEMP            130. F
PUMP CAPACITY     0.3115 CF/REV


                      RESULTS
BAG             1           2           3

VMIX       3632.       6143.       3609.
DF            9.09       13.37       10.09

           MASS EMISSIONS, GRAMS/BAG

CO           67.47        0.69        4.91
HC            3.97        0.92        1.14
NOX          12.03        6.49        9.32
CO2        2588.76     3067.75     2402.92
CARBON      738.82      838.26      658.83
SO2           0.28        0.23        0.00

FUEL
LBS/BAG       1.87        2.13        1.67

                                       INDOLENE MILEAGE
AVERAGE COLD START MILEAGE        11.56 MILES/GAL       4.914 KM/LITRE
AVERAGE HOT START MILEAGE         12.17                 5.177
OVERALL TEST MILEAGE              11.95  12.58          5.084
WEIGHTED TEST MILEAGE             11.90                 5.061


                    WEIGHTED MASS EMISSIONS

           CO        4.334 G/MILE          2.693 G/KM
           HC        0.437                 0.272
           NOX       2.263                 1.406
 CORRECTED NOX       2.181                 1.355
           CO2     740.078               459.863
           SO2       0.047                 0.029
           SO2       0.047                 0.029   UNWEIGHTED
```

```
DATE 9/9/10/7                      VEHICLE NO. 26              MAKE NOVA
STAND 3                            ODOMETER 13,191.2
FUEL INDOLENE

WET BULB TEMP     64               ABSOLUTE HUMIDITY   68.0 GRNS/LBS DRY AIR
DRY BULB TEMP     77               RELATIVE HUMIDITY   49.0 PCT
BAROMETRIC PRES. 767.              PUMP INLET PRES.    20.90 INCHES OF H2O

                               MEASURED CONCENTRATIONS
 BAG             1       AIR(1)       2       AIR(2)       3      AIR(3)

CO,PPM      742.50       3.00       6.00       2.00     73.50      3.00
HC,PPM C6    14.20       0.90       2.90       1.46      5.60      1.22
NOX,PPM      69.50       0.44      20.00       0.28     52.50      0.22
CO2,PCT       1.44       0.04       0.98       0.04      1.35      0.04
SO2,PPM       1.00                  0.00                 0.50

PUMP REV    13414.                 22961.              13392.
TEMP            130. F
PUMP CAPACITY     0.3115 CF/REV


                           RESULTS
BAG            1             2             3

VMIX        3581.         6130.         3575.
DF           8.81         13.64          9.85

              MASS EMISSIONS, GRAMS/BAG

CO          83.55          0.80          7.99
HC           4.70          0.92          1.57
NOX         13.40          6.55         10.12
CO2       2608.37       2997.43       2436.34
CARBON     751.70        819.12        669.65
SO2          0.27          0.00          0.13

FUEL
LBS/BAG       1.91          2.08          1.70

                                       INDOLENE MILEAGE
AVERAGE COLD START MILEAGE        11.60 MILES/GAL       4.934 KM/LITRE
AVERAGE HOT START MILEAGE         12.24                 5.206
OVERALL TEST MILEAGE              11.93  12.45          5.074
WEIGHTED TEST MILEAGE             11.96                 5.085


                         WEIGHTED MASS EMISSIONS

             CO        5.504 G/MILE          3.420 G/KM
             HC        0.513                 0.319
             NOX       2.412                 1.499
   CORRECTED NOX       2.335                 1.451
             CO2     734.366               456.314
             SO2       0.026                 0.016
             SO2       0.037                 0.023   UNWEIGHTED
```

```
DATE 9-8-76                    VEHICLE NO. 26                MAKE NOVA
STAND 2                        ODOMETER 13947.2
FUEL INDOLENE


WET BULB TEMP     80           ABSOLUTE HUMIDITY  140.0 GRNS/LBS DRY AIR
DRY BULB TEMP     90           RELATIVE HUMIDITY   60.0 PCT
BAROMETRIC PRES. 763.          PUMP INLET PRES.     6.80 INCHES OF H2O


                         MEASURED CONCENTRATIONS
 BAG              1       AIR(1)       2      AIR(2)       3      AIR(3)

CO,PPM       1600.00       1.50     800.00     1.50    1760.00     3.00
HC,PPM C6      44.00       1.16      18.00     1.00      34.00     1.14
NOX,PPM        48.00       0.12      17.00     0.10      54.00     0.27
CO2,PCT         1.84       0.01       1.23     0.03       1.88     0.03

PUMP REV      9530.                16370.               9560.
TEMP              120. F
PUMP CAPACITY     0.3170 CF/REV


                       RESULTS
BAG             1          2           3

VMIX          2715.      4663.       2723.
DF              6.64       10.17        6.48

              MASS EMISSIONS, GRAMS/BAG

CO           135.26      117.50      149.03
HC            11.44        7.81        8.81
NOX            7.04        4.27        7.93
CO2         2578.30     2908.89     2619.06
CARBON       771.51      850.97      786.26

FUEL
LBS/BAG        1.96        2.16        1.99

                                     INDOLENE MILEAGE
AVERAGE COLD START MILEAGE       11.23 MILES/GAL      4.777 KM/LITRE
AVERAGE HOT START MILEAGE        11.13                4.734
OVERALL TEST MILEAGE             11.10                4.719
WEIGHTED TEST MILEAGE            11.17                4.752

                    WEIGHTED MASS EMISSIONS

               CO      34.749 G/MILE       21.592 G/KM
               HC       2.367               1.471
               NOX      1.576               0.979
     CORRECTED NOX      2.269               1.410
               CO2    734.724             456.536
```

```
DATE 9-10-76                    VEHICLE NO. 26                  MAKE NOVA
STAND 2                         ODOMETER 13968
FUEL TK 90


WET BULB TEMP     73            ABSOLUTE HUMIDITY  116.0 GRNS/LBS DRY AIR
DRY BULB TEMP     77            RELATIVE HUMIDITY   83.0 PCT
BAROMETRIC PRES. 756.           PUMP INLET PRES.     6.75 INCHES OF H20


                          MEASURED CONCENTRATIONS
 BAG              1       AIR(1)     2       AIR(2)      3       AIR(3)

CO,PPM     2250.00        5.00    760.00       4.00   880.00      5.00
HC,PPM C6    46.00        1.39     18.30       1.60    26.00      2.10
NOX,PPM      48.00        0.22     14.50       0.15    60.50      0.70
CO2,PCT       1.91        0.03      1.23       0.03     1.88      0.04

PUMP REV     9610.                16380.               9590.
TEMP           120. F
PUMP CAPACITY    0.3170 CF/REV


                      RESULTS
BAG             1           2           3

VMIX        2712.        4623.       2706.
DF            6.23        10.20        6.77

                MASS EMISSIONS, GRAMS/BAG

CO          188.07       109.47       73.22
HC           11.91         7.63        6.42
NOX           7.02         3.59        8.78
CO2        2645.07      2873.04     2584.87
CARBON      812.78       837.58      742.35

FUEL
LBS/BAG       2.06         2.13        1.88

                                 INDOLENE MILEAGE
AVERAGE COLD START MILEAGE       11.04 MILES/GAL       4.696 KM/LITRE
AVERAGE HOT START MILEAGE        11.53                 4.906
OVERALL TEST MILEAGE             11.17                 4.751
WEIGHTED TEST MILEAGE            11.32                 4.813


                    WEIGHTED MASS EMISSIONS

                CO       30.943 G/MILE        19.227 G/KM
                HC        2.189                1.360
                NOX       1.549                0.963
      CORRECTED NOX       1.919                1.192
                CO2     731.174              454.330
```

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                                                                  MAKE NOVA
DATE 9-15-76                         VEHICLE NO. 26
STAND 2                              ODOMETER 13994
FUEL TK 90


WET BULB TEMP     72                 ABSOLUTE HUMIDITY  110.0 GRNS/LBS DRY AIR
DRY BULB TEMP     77                 RELATIVE HUMIDITY   79.0 PCT
BAROMETRIC PRES. 768.                PUMP INLET PRES.     6.80 INCHES OF H2O



                              MEASURED CONCENTRATIONS
 BAG              1       AIR(1)     2       AIR(2)     3       AIR(3)

CO,PPM       2500.00        5.00   932.00      6.00  1500.00      4.00
HC,PPM C6      41.00        1.00    16.00      1.16    22.00      1.14
NOX,PPM        56.50        0.30    15.30      0.20    43.50      0.23
CO2,PCT         1.89        0.04     1.16      0.04     1.63      0.04

PUMP REV       9570.               16370.               9590.
TEMP             120. F
PUMP CAPACITY      0.3170 CF/REV



                         RESULTS
 BAG             1           2           3

 VMIX          2744.       4694.       2750.
 DF            6.22       10.64        7.50

              MASS EMISSIONS, GRAMS/BAG

 CO          211.82      136.53      127.97
 HC           10.79        6.87        5.66
 NOX           8.36        3.84        6.45
 CO2        2642.99     2735.50     2275.02
 CARBON      821.43      811.00      680.61

 FUEL
 LBS/BAG       2.08        2.06        1.73
                                        INDOLENE MILEAGE
 AVERAGE COLD START MILEAGE       11.16 MILES/GAL       4.748 KM/LITRE
 AVERAGE HOT START MILEAGE        12.22                 5.196
 OVERALL TEST MILEAGE             11.56                 4.914
 WEIGHTED TEST MILEAGE            11.74                 4.993


                       WEIGHTED MASS EMISSIONS

              CO       40.076 G/MILE        24.902 G/KM
              HC        1.966                1.221
              NOX       1.482                0.920
    CORRECTED NOX       1.773                1.102
              CO2     689.167              428.228
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DATE 9-16-76                VEHICLE NO. 26             MAKE NOVA
STAND 2                     ODOMETER 14015.4
FUEL INDOLENE


WET BULB TEMP     73        ABSOLUTE HUMIDITY  118.0 GRNS/LBS DRY AIR
DRY BULB TEMP     76        RELATIVE HUMIDITY   87.0 PCT
BAROMETRIC PRES. 767.       PUMP INLET PRES.     6.80 INCHES OF H2O


                        MEASURED CONCENTRATIONS
 BAG            1      AIR(1)     2      AIR(2)     3      AIR(3)

CO,PPM       775.00     3.00     8.25     3.00    33.00     3.00
HC,PPM C6     25.00     1.36     2.90     1.46     6.80     1.52
NOX,PPM       45.00     0.18    13.50     0.15    51.50     0.27
CO2,PCT        1.95     0.00     1.31     0.00     2.10     0.00

PUMP REV     9540.              16360.             9590.
TEMP           125. F
PUMP CAPACITY    0.3170 CF/REV



                   RESULTS
BAG  .        1           2           3

VMIX       2709.       4645.       2723.
DF          6.57       10.20        6.35

           MASS EMISSIONS, GRAMS/BAG

CO         64.45        0.79        2.53
HC          6.32        0.72        1.47
NOX         6.58        3.36        7.56
CO2      2739.03     3155.50     2965.18
CARBON    780.58      862.07      811.54

FUEL
LBS/BAG     1.98        2.19        2.06

                                 INDOLENE MILEAGE
AVERAGE COLD START MILEAGE     11.09 MILES/GAL     4.718 KM/LITRE
AVERAGE HOT START MILEAGE      10.89               4.631
OVERALL TEST MILEAGE           10.89               4.632
WEIGHTED TEST MILEAGE          10.98               4.668


                     WEIGHTED MASS EMISSIONS

           CO       3.994 G/MILE        2.481 G/KM
           HC       0.570               0.354
           NOX      1.400               0.870
 CORRECTED NOX      1.755               1.090
           CO2    803.125             499.038
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DATE 9-17-76                  VEHICLE NO. 26                MAKE NOVA
STAND 2                       ODOMETER 14048.2
FUEL TK 90


WET BULB TEMP     75          ABSOLUTE HUMIDITY  126.0 GRNS/LBS DRY AIR
DRY BULB TEMP     78          RELATIVE HUMIDITY   87.0 PCT
BAROMETRIC PRES. 764.         PUMP INLET PRES.     6.70 INCHES OF H2O


                        MEASURED CONCENTRATIONS
 BAG            1       AIR(1)     2      AIR(2)     3       AIR(3)

CO,PPM      920.00      4.00      4.00     2.00    70.00     3.00
HC,PPM C6    28.00      2.30      3.90     2.40     6.00     2.40
NOX,PPM      49.50      0.16     14.60     0.10    41.50     0.15
CO2,PCT       2.04      0.04      1.38     0.03     1.84     0.03

PUMP REV     9550.               16380.             9550.
TEMP           125. F
PUMP CAPACITY    0.3170 CF/REV


                    RESULTS
BAG          1           2           3

VMIX       2701.       4634.       2701.
DF          6.23        9.69        7.24

           MASS EMISSIONS, GRAMS/BAG

CO         76.13        0.31        5.61
HC          6.90        0.79        1.04
NOX         7.22        3.64        6.05
CO2      2817.70     3240.34     2535.32
CARBON    807.55      885.08      695.17

FUEL
LBS/BAG     2.05        2.25        1.76

                                  INDOLENE MILEAGE
AVERAGE COLD START MILEAGE      10.77 MILES/GAL      4.579 KM/LITRE
AVERAGE HOT START MILEAGE       11.53                4.905
OVERALL TEST MILEAGE            11.19                4.761
WEIGHTED TEST MILEAGE           11.19                4.759


                   WEIGHTED MASS EMISSIONS

            CO        4.833 G/MILE        3.003 G/KM
            HC        0.580               0.360
            NOX       1.359               0.844
  CORRECTED NOX       1.788               1.111
            CO2     786.279             488.571
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DATE 9-20-76                   VEHICLE NO. 26                  MAKE NOVA
STAND 2                        ODOMETER 14071.8
FUEL INDOLENE


WET BULB TEMP     70           ABSOLUTE HUMIDITY  102.0 GRNS/LBS DRY AIR
DRY BULB TEMP     75           RELATIVE HUMIDITY   78.0 PCT
BAROMETRIC PRES. 756.          PUMP INLET PRES.     6.70 INCHES OF H20


                          MEASURED CONCENTRATIONS
BAG             1        AIR(1)     2      AIR(2)      3       AIR(3)

CO,PPM       1350.00      3.00     4.00     3.00    135.00      1.50
HC,PPM C6      23.00      1.71     3.00     1.74      6.20      1.44
NOX,PPM        49.00      0.17    16.30     0.15     34.50      0.11
CO2,PCT         2.03      0.04     1.30     0.04      1.80      0.03

PUMP REV     9540.               16380.              9580.
TEMP            125. F
PUMP CAPACITY     0.3170 CF/REV


                     RESULTS
BAG            1           2           3

VMIX        2670.       4584.       2681.
DF             6.17       10.29        7.37

              MASS EMISSIONS, GRAMS/BAG

CO           110.99        0.17       11.10
HC             5.64        0.64        1.30
NOX            7.06        4.01        4.99
CO2         2764.11     3004.45     2466.48
CARBON       806.78      820.52      678.97

FUEL
LBS/BAG        2.05        2.08        1.72
                                       INDOLENE MILEAGE
AVERAGE COLD START MILEAGE        11.20 MILES/GAL         4.763 KM/LITRE
AVERAGE HOT START MILEAGE         12.15                   5.169
OVERALL TEST MILEAGE              11.59                   4.929
WEIGHTED TEST MILEAGE             11.72                   4.986


                   WEIGHTED MASS EMISSIONS

               CO       7.231 G/MILE          4.493 G/KM
               HC       0.508                 0.315
               NOX      1.319                 0.820
     CORRECTED NOX      1.511                 0.939
               CO2    746.522               463.867
```

36 Hour Soak

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DATE 9-21-76                    VEHICLE NO. 26                  MAKE NOVA
STAND 2                         ODOMETER 14094
FUEL TK 90


WET BULB TEMP     68            ABSOLUTE HUMIDITY   96.0 GRNS/LBS DRY AIR
DRY BULB TEMP     72            RELATIVE HUMIDITY   82.0 PCT
BAROMETRIC PRES. 751.           PUMP INLET PRES.     6.70 INCHES OF H2O


                                MEASURED CONCENTRATIONS
 BAG               1       AIR(1)       2      AIR(2)      3       AIR(3)

CO,PPM       1500.00        4.00      4.00      3.00    136.00      3.00
HC,PPM C6      25.00        1.17      2.22      1.10      4.60      0.95
NOX,PPM        57.00        0.24     18.30      0.18     37.50      0.23
CO2,PCT         1.95        0.03      1.29      0.03      1.77      0.04

PUMP REV     9520.                  16390.              9550.
TEMP              125. F
PUMP CAPACITY     0.3170 CF/REV


                      RESULTS
BAG            1            2            3

VMIX        2646.        4556.        2655.
DF            6.36        10.33         7.50

                 MASS EMISSIONS, GRAMS/BAG

CO          122.22         0.17        10.96
HC            6.22         0.54         0.98
NOX           8.14         4.47         5.36
CO2        2635.50      2984.88      2388.89
CARBON      777.01       815.10       657.46

FUEL
LBS/BAG        1.97         2.07         1.67

                                   INDOLENE MILEAGE
AVERAGE COLD START MILEAGE        11.45 MILES/GAL       4.868 KM/LITRE
AVERAGE HOT START MILEAGE         12.38                 5.263
OVERALL TEST MILEAGE              11.88                 5.053
WEIGHTED TEST MILEAGE             11.96                 5.086


                        WEIGHTED MASS EMISSIONS

                 CO        7.863 G/MILE          4.886 G/KM
                 HC        0.504                 0.313
                 NOX       1.471                 0.914
       CORRECTED NOX       1.632                 1.014
                 CO2     730.643               454.000
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DATE 9-28-76                   VEHICLE NO. 26               MAKE NOVA
STAND 2                        ODOMETER 14233
FUEL TK 90


WET BULB TEMP     62           ABSOLUTE HUMIDITY   74.0 GRNS/LBS DRY AIR
DRY BULB TEMP     68           RELATIVE HUMIDITY   73.0 PCT
BAROMETRIC PRES. 759.          PUMP INLET PRES.     6.80 INCHES OF H2O


                        MEASURED CONCENTRATIONS
 BAG              1       AIR(1)      2       AIR(2)      3      AIR(3)

CO,PPM      1850.00       6.00      4.00      2.00     46.00     3.00
HC,PPM C6     34.00       0.74      2.10      0.66      6.10     0.73
NOX,PPM       85.00       0.20     29.50      0.13     68.50     0.22
CO2,PCT        1.78       0.03      1.22      0.03      1.53     0.03

PUMP REV     9560.                16450.               9570.
TEMP            120. F
PUMP CAPACITY    0.3170 CF/REV



                   RESULTS
BAG            1          2          3

VMIX        2709.      4661.      2711.
DF          6.76       10.95       8.68

           MASS EMISSIONS, GRAMS/BAG

CO        155.21        0.31       3.66
HC          8.85        0.68       1.44
NOX        12.44        7.41      10.03
CO2      2465.40     2874.28    2114.85
CARBON    747.01      785.09     579.95

FUEL
LBS/BAG     1.90        1.99       1.47

                                  INDOLENE MILEAGE
AVERAGE COLD START MILEAGE      11.89 MILES/GAL     5.059 KM/LITRE
AVERAGE HOT START MILEAGE       13.35               5.678
OVERALL TEST MILEAGE            12.66               5.382
WEIGHTED TEST MILEAGE           12.68               5.394


                 WEIGHTED MASS EMISSIONS

           CO        9.219 G/MILE        5.728 G/KM
           HC        0.709               0.440
           NOX       2.465               1.531
 CORRECTED NOX       2.453               1.524
           CO2     685.315             425.835
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DATE 9-29-76                          VEHICLE NO. 26                    MAKE NOVA
STAND 2                               ODOMETER 14256
FUEL TK 90


WET BULB TEMP     58                  ABSOLUTE HUMIDITY   64.0 GRNS/LBS DRY AIR
DRY BULB TEMP     63                  RELATIVE HUMIDITY   74.0 PCT
BAROMETRIC PRES. 762.                 PUMP INLET PRES.     6.70 INCHES OF H2O


                                 MEASURED CONCENTRATIONS
 BAG              1          AIR(1)        2         AIR(2)        3        AIR(3)

CO,PPM     1800.00           2.00        3.00        2.00       50.00        2.00
HC,PPM C6    32.00           0.68        2.00        0.62        5.40        0.64
NOX,PPM     102.00           0.27       30.00        0.35       74.00        0.45
CO2,PCT       1.97           0.03        1.21        0.04        1.61        0.04

PUMP REV      9550.                    16400.                    9540.
TEMP              120. F
PUMP CAPACITY       0.3170 CF/REV


                        RESULTS
BAG             1             2             3

VMIX          2717.         4667.         2714.
DF              6.20         11.06          8.28

                 MASS EMISSIONS, GRAMS/BAG

CO            151.17          0.16          4.07
HC              8.36          0.65          1.28
NOX            14.98          7.50         10.82
CO2          2734.69       2840.08       2216.88
CARBON        818.34        775.67        607.83

FUEL
LBS/BAG        2.08          1.97          1.54

                                           INDOLENE MILEAGE
AVERAGE COLD START MILEAGE           11.43 MILES/GAL        4.862 KM/LITRE
AVERAGE HOT START MILEAGE            13.17                  5.602
OVERALL TEST MILEAGE                 12.14                  5.163
WEIGHTED TEST MILEAGE                12.36                  5.258


                             WEIGHTED MASS EMISSIONS

                 CO         8.999 G/MILE            5.591 G/KM
                 HC         0.665                   0.413
                 NOX        2.681                   1.666
       CORRECTED NOX        2.549                   1.584
                 CO2      703.950                 437.414
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DATE 9-30-76                     VEHICLE NO. 26                  MAKE NOVA
STAND 2                          ODOMETER 14279
FUEL TK 90

WET BULB TEMP      62            ABSOLUTE HUMIDITY   76.0 GRNS/LBS DRY AIR
DRY BULB TEMP      66.5          RELATIVE HUMIDITY   78.0 PCT
BAROMETRIC PRES. 760.            PUMP INLET PRES.     6.75 INCHES OF H2O


                          MEASURED CONCENTRATIONS
 BAG              1        AIR(1)      2        AIR(2)      3        AIR(3)

CO,PPM       1750.00      16.00      12.00      10.50      39.50      13.50
HC,PPM C6      28.00       1.18       2.70       1.17       4.80       1.02
NOX,PPM        79.50       0.55      24.70       0.50      63.50       0.31
CO2,PCT         1.83       0.05       1.21       0.04       1.61       0.04

PUMP REV       9600.                16360.                 9570.
TEMP              120. F
PUMP CAPACITY     0.3170 CF/REV


                     RESULTS
BAG             1            2            3

VMIX         2724.        4642.        2715.
DF              6.66        11.04         8.28

            MASS EMISSIONS, GRAMS/BAG

CO          146.50         0.32         2.30
HC            7.20         0.74         1.03
NOX          11.66         6.09         9.30
CO2        2525.02      2825.25      2217.64
CARBON      758.12       771.77       607.06

FUEL
LBS/BAG        1.92         1.96         1.54

                                      INDOLENE MILEAGE
AVERAGE COLD START MILEAGE        11.91 MILES/GAL      5.066 KM/LITRE
AVERAGE HOT START MILEAGE         13.22                5.621
OVERALL TEST MILEAGE              12.51                5.319
WEIGHTED TEST MILEAGE             12.62                5.368


                        WEIGHTED MASS EMISSIONS

               CO        8.617 G/MILE          5.354 G/KM
               HC        0.591                 0.367
               NOX       2.188                 1.359
     CORRECTED NOX       2.198                 1.366
               CO2     690.009               428.751
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DATE 10-12-76                       VEHICLE NO. 26                  MAKE NOVA
STAND 2                             ODOMETER 14457
FUEL TK 90


WET BULB TEMP     61                ABSOLUTE HUMIDITY   66.0 GRNS/LBS DRY AIR
DRY BULB TEMP     70                RELATIVE HUMIDITY   60.0 PCT
BAROMETRIC PRES. 771.               PUMP INLET PRES.     6.80 INCHES OF H2O



                              MEASURED CONCENTRATIONS
 BAG              1        AIR(1)       2        AIR(2)       3        AIR(3)

CO,PPM     1100.00          5.00      5.00        3.00     37.00        3.00
HC,PPM C6    21.00          1.61      2.80        1.33      6.20        1.13
NOX,PPM      71.00          0.38     20.00        0.17     51.00        0.28
CO2,PCT       1.92          0.05      1.31        0.06      1.76        0.06

PUMP REV     9560.               16360.                    9570.
TEMP              125. F
PUMP CAPACITY    0.3170 CF/REV



                        RESULTS
BAG            1            2            3

VMIX        2729.        4670.        2731.
DF           6.56        10.17         7.58

            MASS EMISSIONS, GRAMS/BAG

CO          93.01         0.32         2.92
HC           5.25         0.73         1.39
NOX         10.44         5.02         7.51
CO2       2663.97      3053.33      2419.29
CARBON     771.41       834.00       662.67

FUEL
LBS/BAG      1.96         2.12         1.68

                                    INDOLENE MILEAGE
AVERAGE COLD START MILEAGE       11.35 MILES/GAL      4.828 KM/LITRE
AVERAGE HOT START MILEAGE        12.18                5.178
OVERALL TEST MILEAGE             11.78                5.012
WEIGHTED TEST MILEAGE            11.81                5.022


                        WEIGHTED MASS EMISSIONS

               CO        5.598 G/MILE         3.478 G/KM
               HC        0.504                0.313
               NOX       1.839                1.142
     CORRECTED NOX       1.764                1.096
               CO2     743.711              462.121
```

```
DATE 10-13-76                      VEHICLE NO. 26                   MAKE NOVA
STAND 2                            ODOMETER 14479
FUEL TK 90


WET BULB TEMP     62               ABSOLUTE HUMIDITY    70.0 GRNS/LBS DRY AIR
DRY BULB TEMP     70               RELATIVE HUMIDITY    64.0 PCT
BAROMETRIC PRES. 761.              PUMP INLET PRES.      6.75 INCHES OF H2O


                             MEASURED CONCENTRATIONS
 BAG              1        AIR(1)       2       AIR(2)       3       AIR(3)

CO,PPM        980.00        4.00      10.00      5.00     102.00      3.00
HC,PPM C6      22.00        0.90       2.20      0.87       5.40      0.86
NOX,PPM        70.00        0.21      25.00      0.29      52.00      0.15
CO2,PCT         1.97        0.06       1.28      0.06       1.76      0.05

PUMP REV      9550.                   16380.                9540.
TEMP              125. F
PUMP CAPACITY     0.3170 CF/REV



                        RESULTS
BAG             1            2            3

VMIX         2690.        4614.        2687.
DF             6.44         10.38        7.54

                  MASS EMISSIONS, GRAMS/BAG

CO            81.54         0.77          8.31
HC             5.59         0.63          1.22
NOX           10.17         6.18          7.55
CO2         2684.59      2951.02       2395.82
CARBON       772.42       806.20        658.43

FUEL
LBS/BAG        1.96         2.05          1.67

                                     INDOLENE MILEAGE
AVERAGE COLD START MILEAGE         11.54 MILES/GAL        4.910 KM/LITRE
AVERAGE HOT START MILEAGE          12.44                  5.292
OVERALL TEST MILEAGE               11.95                  5.081
WEIGHTED TEST MILEAGE              12.04                  5.120


                      WEIGHTED MASS EMISSIONS

                CO        5.411 G/MILE          3.362 G/KM
                HC        0.499                 0.310
                NOX       1.981                 1.231
      CORRECTED NOX       1.936                 1.203
                CO2     729.470               453.271
```

```
DATE 10-14-76                        VEHICLE NO. 26                    MAKE NOVA
STAND 2                              ODOMETER 14503
FUEL TK 90


WET BULB TEMP     65                 ABSOLUTE HUMIDITY    75.0 GRNS/LBS DRY AIR
DRY BULB TEMP     76                 RELATIVE HUMIDITY    56.0 PCT
BAROMETRIC PRES. 753.                PUMP INLET PRES.      6.70 INCHES OF H2O


                              MEASURED CONCENTRATIONS
 BAG             1        AIR(1)       2       AIR(2)       3       AIR(3)

CO,PPM      2100.00      10.50       5.00      3.50      87.00      1.50
HC,PPM C6     28.00       0.94       2.30      0.86       6.20      0.78
NOX,PPM       69.00       0.20      29.50      0.08      49.50      0.18
CO2,PCT        1.88       0.04       1.19      0.04       1.67      0.04

PUMP REV      9550.                16390.                 9570.
TEMP              125. F
PUMP CAPACITY     0.3170 CF/REV



                         RESULTS
BAG            1            2             3

VMIX        2662.        4568.         2667.
DF           6.39        11.24          7.96

            MASS EMISSIONS, GRAMS/BAG

CO         173.55         0.25          7.15
HC           7.09         0.67          1.44
NOX          9.92         7.28          7.12
CO2       2548.48      2732.78       2261.63
CARBON     776.02       746.45        621.50

FUEL
LBS/BAG      1.97         1.89          1.58

                                         INDOLENE MILEAGE
AVERAGE COLD START MILEAGE          11.97 MILES/GAL      5.091 KM/LITRE
AVERAGE HOT START MILEAGE           13.32                5.666
OVERALL TEST MILEAGE                12.47                5.302
WEIGHTED TEST MILEAGE               12.71                5.403


                     WEIGHTED MASS EMISSIONS

                CO        10.527 G/MILE        6.541 G/KM
                HC         0.607               0.377
                NOX        2.081               1.293
      CORRECTED NOX        2.081               1.293
                CO2      682.368             424.003
```

```
DATE 10-15-76                    VEHICLE NO. 26                   MAKE NOVA
STAND 2                          ODOMETER 14525
FUEL TK 90


WET BULB TEMP     65             ABSOLUTE HUMIDITY   76.0 GRNS/LBS DRY AIR
DRY BULB TEMP     75             RELATIVE HUMIDITY   58.0 PCT
BAROMETRIC PRES. 759.            PUMP INLET PRES.     6.75 INCHES OF H2O


                            MEASURED CONCENTRATIONS
 BAG             1        AIR(1)      2       AIR(2)      3        AIR(3)

CO,PPM      1600.00       10.50     14.00      6.00    215.00       1.50
HC,PPM C6     29.00        0.91      2.40      0.76      5.30       0.65
NOX,PPM       72.50        0.50     32.00      0.40     55.00       0.18
CO2,PCT        1.88        0.05      1.25      0.04      1.65       0.05

PUMP REV     9550.                 16390.              ~~14270.~~
                                                        9580
TEMP            128. F
PUMP CAPACITY     0.3170 CF/REV


                       RESULTS
BAG             1             2            3
                                                  3989 x 9580 = 2678
VMIX         2669.          4581.        3989.           -----
DF              6.54          10.69        8.00          14270

              MASS EMISSIONS, GRAMS/BAG

CO           132.33           1.21        26.68   x  2678  =  17.911
HC             7.38           0.76         1.84      ----  =  1.235
NOX           10.42           7.85        11.84      3989  =  7.949
CO2         2543.78        2883.50      3322.39            =  2230.45
CARBON       757.31         788.07       919.69            =  617.46

FUEL
LBS/BAG        1.92           2.00         2.33          =   1.564
                                           INDOLENE MILEAGE
AVERAGE COLD START MILEAGE        11.79 MILES/GAL       5.015 KM/LITRE
AVERAGE HOT START MILEAGE         10.67                 4.538
OVERALL TEST MILEAGE              10.84 = 12.354        4.611
WEIGHTED TEST MILEAGE             11.13                 4.732


                    WEIGHTED MASS EMISSIONS

               CO       ~~9.777~~ G/MILE 9.109   6.075 G/KM
               HC          0.666     0.618       0.414
               NOX         2.544     2.248       1.581
     CORRECTED NOX         2.556     2.259       1.588
               CO2       782.813   699.824     486.417
```

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                                VEHICLE NO. 26                MAKE NOVA
DATE 10-20-76                   ODOMETER 14549
STAND 2
FUEL TK 90


                                ABSOLUTE HUMIDITY   84.0 GRNS/LBS DRY AIR
WET BULB TEMP     66            RELATIVE HUMIDITY   69.0 PCT
DRY BULB TEMP     73            PUMP INLET PRES.     6.85 INCHES OF H2O
BAROMETRIC PRES. 766.


                        MEASURED CONCENTRATIONS
BAG               1       AIR(1)      2      AIR(2)      3       AIR(3)

CO,PPM         310.00     10.50      8.00     6.00     44.50     6.00
HC,PPM C6       16.80      1.50      2.60     1.32      5.50     1.10
NOX,PPM         69.50      0.47     27.00     0.42     53.00     0.33
CO2,PCT          1.84      0.05      1.16     0.05      1.57     0.05

PUMP REV       9540.               16380.              9550.
TEMP              123. F
PUMP CAPACITY      0.3170 CF/REV



                     RESULTS
BAG              1           2            3

VMIX          2714.        4660.        2717.
DF               7.13        11.52         8.49

             MASS EMISSIONS, GRAMS/BAG

CO              25.35         0.35         3.31
HC               4.12         0.63         1.20
NOX             10.15         6.71         7.75
CO2           2529.12      2692.78      2149.79
CARBON         704.62       735.54       589.12

FUEL
LBS/BAG          1.79         1.87         1.49

                                   INDOLENE MILEAGE
AVERAGE COLD START MILEAGE         12.65 MILES/GAL      5.382 KM/LITRE
AVERAGE HOT START MILEAGE          13.76                5.851
OVERALL TEST MILEAGE               13.17                5.602
WEIGHTED TEST MILEAGE              13.26                5.639


                      WEIGHTED MASS EMISSIONS

                CO        1.752 G/MILE         1.088 G/KM
                HC        0.413                0.256
                NOX       2.067                1.284
      CORRECTED NOX       2.159                1.341
                CO2     667.425              414.718
```

```
DATE 10-21-76                     VEHICLE NO. 26                MAKE NOVA
STAND 2                           ODOMETER 14571
FUEL TK 90


WET BULB TEMP     65              ABSOLUTE HUMIDITY   73.0 GRNS/LBS DRY AIR
DRY BULB TEMP     77              RELATIVE HUMIDITY   53.0 PCT
BAROMETRIC PRES. 753.             PUMP INLET PRES.     6.70 INCHES OF H2O


                             MEASURED CONCENTRATIONS
 BAG              1       AIR(1)      2       AIR(2)      3       AIR(3)

CO,PPM         243.00      1.50      5.00      2.00     38.00     ~~1.00~~ 1.50
HC,PPM C6       13.40      0.80      2.20      0.76      4.70      0.68
NOX,PPM         83.00      0.13     33.00      0.17     65.00      0.16
CO2,PCT          1.86      0.03      1.15      0.04      1.59      0.04

PUMP REV       9560.               16390.               9570.
TEMP               120. F
PUMP CAPACITY       0.3180 CF/REV


                     RESULTS
BAG            1            2            3

VMIX         2696.        4622.        2699.
DF            7.08        11.63         8.39

              MASS EMISSIONS, GRAMS/BAG

CO           20.34         0.45         3.14
HC            3.35         0.68         1.08
NOX          12.10         8.22         9.48
CO2        2564.45      2668.87      2176.00
CARBON      711.45       729.10       596.10

FUEL
LBS/BAG       1.80         1.85         1.51
                                          INDOLENE MILEAGE
AVERAGE COLD START MILEAGE        12.65 MILES/GAL       5.380 KM/LITRE
AVERAGE HOT START MILEAGE         13.75                 5.849
OVERALL TEST MILEAGE              13.12                 5.581
WEIGHTED TEST MILEAGE             13.26                 5.638


                   WEIGHTED MASS EMISSIONS

               CO        1.466 G/MILE        0.911 G/KM
               HC        0.365               0.227
               NOX       2.511               1.560
     CORRECTED NOX       2.487               1.545
               CO2     668.254             415.234
```

```
DATE 10-26-76                        VEHICLE NO. 26                    MAKE NOVA
STAND 2                              ODOMETER 14640
FUEL TK 90


WET BULB TEMP      63                ABSOLUTE HUMIDITY    72.0 GRNS/LBS DRY AIR
DRY BULB TEMP      72                RELATIVE HUMIDITY    62.0 PCT
BAROMETRIC PRES. 756.                PUMP INLET PRES.      6.75 INCHES OF H2O


                              MEASURED CONCENTRATIONS
 BAG                1        AIR(1)       2       AIR(2)       3        AIR(3)

CO,PPM         698.00          3.50      3.50      1.50     77.50        2.00
HC,PPM C6       19.80          1.02      2.60      0.94      5.50        0.88
NOX,PPM         63.00          0.17     20.50      0.13     42.00        0.14
CO2,PCT          1.82          0.04      1.16      0.04      1.65        0.04

PUMP REV       9540.                   16400.               9560.
TEMP               125. F
PUMP CAPACITY      0.3170 CF/REV



                        RESULTS
BAG              1              2              3

VMIX          2669.          4589.          2675.
DF               7.06          11.53          8.06

                 MASS EMISSIONS, GRAMS/BAG

CO              57.79          0.30           6.33
HC               4.95          0.78           1.23
NOX              9.08          5.06           6.06
CO2           2471.93       2673.57        2240.30
CARBON         703.64        730.40         615.15

FUEL
LBS/BAG          1.78          1.85           1.56

                                           INDOLENE MILEAGE
AVERAGE COLD START MILEAGE           12.71 MILES/GAL        5.405 KM/LITRE
AVERAGE HOT START MILEAGE            13.54                  5.760
OVERALL TEST MILEAGE                 13.04                  5.547
WEIGHTED TEST MILEAGE                13.17                  5.602


                          WEIGHTED MASS EMISSIONS

                CO          3.835 G/MILE          2.383 G/KM
                HC          0.482                 0.299
                NOX         1.657                 1.030
      CORRECTED NOX         1.634                 1.015
                CO2       668.464               415.364
```

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                                     VEHICLE NO. 26                    MAKE NOVA
DATE 10-29-76
STAND 2                              ODOMETER 14841
FUEL TK 90

                                     ABSOLUTE HUMIDITY    65.0 GRNS/LBS DRY AIR
WET BULB TEMP     63                 RELATIVE HUMIDITY    ~~47.0~~ PCT 48.0
DRY BULB TEMP     76                 PUMP INLET PRES.      6.90 INCHES OF H2O
BAROMETRIC PRES. 765.


                              MEASURED CONCENTRATIONS
 BAG              1        AIR(1)       2       AIR(2)      3       AIR(3)

CO,PPM         570.00       6.00       9.00      3.50     73.50      1.50
HC,PPM C6       22.00       1.02       2.40      0.90      5.10      0.88
NOX,PPM         62.00       0.22      24.30      0.16     44.50      0.08
CO2,PCT          1.73       0.05       1.15      0.04      1.59      0.04

PUMP REV       9550.                 16380.                9540.
TEMP             120. F
PUMP CAPACITY     0.3170 CF/REV


                         RESULTS
BAG             1           2           3

VMIX          2727.       4677.       2724.
DF               7.45       11.62        8.37

              MASS EMISSIONS, GRAMS/BAG

CO              48.30        0.85        6.18
HC               5.64        0.72        1.15
NOX              9.12        6.11        6.55
CO2           2385.19     2700.60     2196.32
CARBON         676.50      737.96      603.01

FUEL
LBS/BAG          1.72        1.87        1.53
                                         INDOLENE MILEAGE
AVERAGE COLD START MILEAGE        12.88 MILES/GAL      5.479 KM/LITRE
AVERAGE HOT START MILEAGE         13.59                5.780
OVERALL TEST MILEAGE              13.25                5.634
WEIGHTED TEST MILEAGE             13.28                5.647


                          WEIGHTED MASS EMISSIONS

                  CO         3.353 G/MILE         2.083 G/KM
                  HC         0.507                0.315
                  NOX        1.837                1.141
        CORRECTED NOX        1.755                1.090
                  CO2      663.752              412.436
```

```
DATE 11-5-76                      VEHICLE NO. 26                    MAKE NOVA
STAND 2                           ODOMETER 15140
FUEL TK 90

WET BULB TEMP      62.5           ABSOLUTE HUMIDITY    66.0 GRNS/LBS DRY AIR
DRY BULB TEMP      74             RELATIVE HUMIDITY    53.0 PCT
BAROMETRIC PRES. 761.             PUMP INLET PRES.      6.80 INCHES OF H2O


                                 MEASURED CONCENTRATIONS
 BAG              1         AIR(1)       2        AIR(2)       3        AIR(3)

CO,PPM        745.00         5.00      10.50       3.00     130.00       3.00
HC,PPM C6      25.00         1.60       2.60       1.10       6.10       2.10
NOX,PPM        59.00         0.28      27.00       0.23      41.50       0.22
CO2,PCT         1.84         0.05       1.25       0.05       1.65       0.05

PUMP REV      9560.                   16380.                 9570.
TEMP             122. F
PUMP CAPACITY     0.3170 CF/REV


                          RESULTS
BAG             1              2              3

VMIX        2706.          4638.          2709.
DF             6.95          10.69           8.04

                 MASS EMISSIONS, GRAMS/BAG

CO            62.62           1.13          10.81
HC             6.26           0.72           1.13
NOX            8.61           6.73           6.06
CO2         2522.48        2897.08        2256.80
CARBON       720.64         791.70         621.48

FUEL
LBS/BAG        1.83           2.01           1.58

                                        INDOLENE MILEAGE
AVERAGE COLD START MILEAGE          12.05 MILES/GAL        5.125 KM/LITRE
AVERAGE HOT START MILEAGE           12.90                  5.484
OVERALL TEST MILEAGE                12.53                  5.327
WEIGHTED TEST MILEAGE               12.52                  5.324


                      WEIGHTED MASS EMISSIONS

               CO        4.563 G/MILE          2.835 G/KM
               HC        0.542                 0.337
               NOX       1.852                 1.150
     CORRECTED NOX       1.776                 1.104
               CO2     702.418               436.462
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DATE 3-4-77                       VEHICLE NO. 26                  MAKE NOVA
STAND 2                           ODOMETER 16548
FUEL INDOLENE


WET BULB TEMP     58              ABSOLUTE HUMIDITY   58.0 GRNS/LBS DRY AIR
DRY BULB TEMP     67              RELATIVE HUMIDITY   58.0 PCT
BAROMETRIC PRES. 768.             PUMP INLET PRES.     7.00 INCHES OF H2O


                             MEASURED CONCENTRATIONS
 BAG              1        AIR(1)      2       AIR(2)      3       AIR(3)

CO,PPM     1230.00        7.00       5.30      3.50    127.00      3.00
HC,PPM C6    38.00        1.12       3.80      1.24     13.00      2.80
NOX,PPM      68.00        0.68      37.00      0.56     62.00      0.48
CO2,PCT       1.88        0.05       1.29      0.05      1.73      0.05

PUMP REV     9550.                 16450.               9540.
TEMP             120. F
PUMP CAPACITY    0.3170 CF/REV


                       RESULTS
BAG             1             2             3

VMIX        2737.          4715.         2734.
DF            6.63          10.32          7.65

                  MASS EMISSIONS, GRAMS/BAG

CO          104.39           0.30         10.62
HC            9.93           1.23          2.83
NOX           9.99           9.32          9.12
CO2        2608.20        3055.78       2391.35
CARBON      765.12         835.10        659.59

FUEL
LBS/BAG       1.94           2.12          1.67

                                        INDOLENE MILEAGE
AVERAGE COLD START MILEAGE          11.39 MILES/GAL       4.843 KM/LITRE
AVERAGE HOT START MILEAGE           12.19                 5.185
OVERALL TEST MILEAGE                11.83                 5.030
WEIGHTED TEST MILEAGE               11.83                 5.033


                         WEIGHTED MASS EMISSIONS

                 CO       6.833 G/MILE         4.245 G/KM
                 HC       0.949                0.590
                 NOX      2.508                1.559
       CORRECTED NOX      2.323                1.443
                 CO2    738.718              459.018
```

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DATE 3-8-77                         VEHICLE NO. 26                  MAKE NOVA
STAND 2                             ODOMETER 16576
FUEL INDOLENE


WET BULB TEMP     60                ABSOLUTE HUMIDITY   61.0 GRNS/LBS DRY AIR
DRY BULB TEMP     71                RELATIVE HUMIDITY   55.0 PCT
BAROMETRIC PRES. 769.               PUMP INLET PRES.     7.10 INCHES OF H2O


                              MEASURED CONCENTRATIONS
 BAG              1       AIR(1)      2       AIR(2)      3       AIR(3)

CO,PPM        853.00       5.90      5.30      1.50    157.50      3.00
HC,PPM C6      36.00       1.06      5.20      2.60      8.70      1.37
NOX,PPM        86.00       0.41     37.50      0.23     75.00      0.20
CO2,PCT         1.86       0.05      1.31      0.04      1.77      0.05

PUMP REV      9550.                16370.              9540.
TEMP              120. F
PUMP CAPACITY      0.3170 CF/REV


                         RESULTS
BAG              1          2          3

VMIX          2740.      4697.      2737.
DF             6.82      10.20       7.48

                 MASS EMISSIONS, GRAMS/BAG

CO            72.49       0.57      13.24
HC             9.42       1.31       2.01
NOX           12.71       9.48      11.09
CO2         2582.29    3102.85    2450.92
CARBON       743.93     848.13     676.26

FUEL
LBS/BAG        1.89       2.15       1.72
                                          INDOLENE MILEAGE
AVERAGE COLD START MILEAGE             11.45 MILES/GAL      4.868 KM/LITRE
AVERAGE HOT START MILEAGE              11.96                5.084
OVERALL TEST MILEAGE                   11.78                5.011
WEIGHTED TEST MILEAGE                  11.73                4.989


                        WEIGHTED MASS EMISSIONS

                 CO        5.240 G/MILE        3.256 G/KM
                 HC        0.868               0.539
                 NOX       2.837               1.762
       CORRECTED NOX       2.661               1.654
                 CO2     748.034             464.807
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DATE 4 22 77                    VEHICLE NO. 26                MAKE NOVA
STAND 2                         ODOMETER 16784
FUEL INDOLENE


WET BULB TEMP    60             ABSOLUTE HUMIDITY   66.0 GRNS/LBS DRY AIR
DRY BULB TEMP    67             RELATIVE HUMIDITY   67.0 PCT
BAROMETRIC PRES. 754.           PUMP INLET PRES.     7.00 INCHES OF H2O



                          MEASURED CONCENTRATIONS
 BAG            1       AIR(1)       2       AIR(2)       3      AIR(3)

CO,PPM     1275.00       8.80      7.90       3.00    133.00      3.00
HC,PPM C6    29.00       1.18      3.30       1.00      7.30      1.06
NOX,PPM      74.00       0.50     36.00       0.45     68.50      0.50
CO2,PCT       1.81       0.04      1.19       0.03      1.62      0.04

PUMP REV     9560.               16380.                9540.
TEMP           120. F
PUMP CAPACITY    0.3170 CF/REV



                     RESULTS
BAG            1            2            3

VMIX        2689.        4608.        2683.
DF           6.84        11.22         8.16

            MASS EMISSIONS, GRAMS/BAG

CO         106.00         0.74        10.91
HC           7.37         1.07         1.67
NOX         10.71         8.88         9.89
CO2       2483.07      2769.58      2212.54
CARBON     729.45       757.05       609.91

FUEL
LBS/BAG      1.85         1.92         1.55

                                    INDOLENE MILEAGE
AVERAGE COLD START MILEAGE       12.26 MILES/GAL      5.214 KM/LITRE
AVERAGE HOT START MILEAGE        13.33                5.670
OVERALL TEST MILEAGE             12.75                5.422
WEIGHTED TEST MILEAGE            12.85                5.464

                    WEIGHTED MASS EMISSIONS

            CO        7.006 G/MILE        4.353 G/KM
            HC        0.694               0.431
            NOX       2.550               1.584
  CORRECTED NOX       2.447               1.520
            CO2     679.793             422.404
```

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DATE 3 23 77                    VEHICLE NO. 26                 MAKE NOVA
STAND 2                         ODOMETER 16824
FUEL INDOLENE


WET BULB TEMP     58            ABSOLUTE HUMIDITY   58.0 GRNS/LBS DRY AIR
DRY BULB TEMP     67            RELATIVE HUMIDITY   58.0 PCT
BAROMETRIC PRES. 752.           PUMP INLET PRES.     6.90 INCHES OF H2O


                          MEASURED CONCENTRATIONS
 BAG              1       AIR(1)      2       AIR(2)      3       AIR(3)

CO,PPM     1100.00        3.00     11.50      5.00    105.50      2.00
HC,PPM C6    37.00        1.12      3.50      1.02     11.60      0.80
NOX,PPM      76.00        0.29     52.00      0.20     76.50      0.38
CO2,PCT       1.88        0.04      1.32      0.04      1.59      0.04

PUMP REV     9550.               16390.                9550.
TEMP           120. F
PUMP CAPACITY     0.3170 CF/REV


                  RESULTS
BAG            1            2            3

VMIX       2680.        4599.        2680.
DF          6.65        10.08         8.33

           MASS EMISSIONS, GRAMS/BAG

CO         91.62         0.99         8.70
HC          9.46         1.16         2.86
NOX        10.99        12.90        11.05
CO2      2575.07      3063.43      2155.93
CARBON    750.20       837.42       594.55

FUEL
LBS/BAG      1.90         2.12         1.51

                                      INDOLENE MILEAGE
AVERAGE COLD START MILEAGE      11.48 MILES/GAL      4.882 KM/LITRE
AVERAGE HOT START MILEAGE       12.73                5.412
OVERALL TEST MILEAGE            12.25                5.209
WEIGHTED TEST MILEAGE           12.16                5.171


                   WEIGHTED MASS EMISSIONS

            CO        6.048 G/MILE        3.758 G/KM
            HC        0.915               0.568
            NOX       3.191               1.983
  CORRECTED NOX       2.955               1.836
            CO2     719.945             447.353
```

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DATE 4 11 77                      VEHICLE NO. 26                  MAKE NOVA
STAND 3                           ODOMETER 18283.4
FUEL TK90

WET BULB TEMP     62              ABSOLUTE HUMIDITY   67.0 GRNS/LBS DRY AIR
DRY BULB TEMP     72              RELATIVE HUMIDITY   57.0 PCT
BAROMETRIC PRES. 773.             PUMP INLET PRES.    21.90 INCHES OF H2O


                             MEASURED CONCENTRATIONS
BAG               1        AIR(1)      2        AIR(2)      3       AIR(3)

CO,PPM         947.50       3.00       6.00      3.00      98.00      3.00
HC,PPM C6       27.00       0.74       2.50      1.06       5.00      0.76
NOX,PPM         41.50       0.37      26.50      0.26      40.00      0.17
CO2,PCT          1.42       0.00       0.95      0.00       1.27      0.00

PUMP REV     12270.                  21240.               12370.
TEMP               120. F
PUMP CAPACITY       0.3120 CF/REV


                         RESULTS
BAG              1          2           3

VMIX          3357.       5811.       3384.
DF               8.74       14.07       10.38

              MASS EMISSIONS, GRAMS/BAG

CO              99.77        0.58       10.16
HC               8.66        0.86        1.43
NOX              7.48        8.26        7.30
CO2           2482.10     2862.42     2242.62
CARBON         727.63      782.13      617.59

FUEL
LBS/BAG          1.85        1.98        1.57
                                           INDOLENE MILEAGE
AVERAGE COLD START MILEAGE           12.07 MILES/GAL       5.134 KM/LITRE
AVERAGE HOT START MILEAGE            13.02                 5.537
OVERALL TEST MILEAGE                 12.56                 5.343
WEIGHTED TEST MILEAGE                12.59                 5.356


                        WEIGHTED MASS EMISSIONS

                 CO          6.570 G/MILE          4.082 G/KM
                 HC          0.720                 0.447
                 NOX         2.086                 1.296
       CORRECTED NOX         2.010                 1.249
                 CO2       694.404               431.482
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DATE 4 12 77                          VEHICLE NO. 26                MAKE NOVA
STAND 3                               ODOMETER 18304.4
FUEL CK31175


WET BULB TEMP     63.0                ABSOLUTE HUMIDITY   66.5 GRNS/LBS DRY AIR
DRY BULB TEMP     75.0                RELATIVE HUMIDITY   51.0 PCT
BAROMETRIC PRES. 768.                 PUMP INLET PRES.    21.80 INCHES OF H2O



                                 MEASURED CONCENTRATIONS
 BAG              1        AIR(1)      2        AIR(2)       3        AIR(3)

CO,PPM        930.00        8.75      7.00       3.00      75.50       5.00
HC,PPM C6      25.60        0.68      2.40       0.63       4.36       0.72
NOX,PPM        40.50        0.16     23.60       0.00      36.50       0.07
CO2,PCT         1.45        0.04      0.90       0.04       1.27       0.04

PUMP REV     12430.                  21220.                12430.
TEMP            120. F
PUMP CAPACITY     0.3107 CF/REV



                       RESULTS
BAG             1              2           3

VMIX         3364.          5744.       3364.
DF            8.57          14.85       10.40

              MASS EMISSIONS, GRAMS/BAG

CO           97.73           0.75        7.53
HC            8.24           1.02        1.22
NOX           7.35           7.34        6.64
CO2        2482.11        2569.50     2166.64
CARBON      726.39         702.40      595.55

FUEL
LBS/BAG        1.84           1.78        1.51

                                             INDOLENE MILEAGE
AVERAGE COLD START MILEAGE          12.76 MILES/GAL       5.424 KM/LITRE
AVERAGE HOT START MILEAGE           14.04                 5.971
OVERALL TEST MILEAGE                13.20                 5.615
WEIGHTED TEST MILEAGE               13.46                 5.723


                         WEIGHTED MASS EMISSIONS

               CO        6.277 G/MILE         3.900 G/KM
               HC        0.701                0.435
               NOX       1.905                1.183
     CORRECTED NOX       1.832                1.138
               CO2     649.573              403.626
```

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DATE 4 19 77                    VEHICLE NO. 26                MAKE NOVA
STAND 2                         ODOMETER 18328
FUEL INDOLENE


WET BULB TEMP     63            ABSOLUTE HUMIDITY   66.0 GRNS/LBS DRY AIR
DRY BULB TEMP     76            RELATIVE HUMIDITY   48.0 PCT
BAROMETRIC PRES. 767.           PUMP INLET PRES.     6.90 INCHES OF H2O


                         MEASURED CONCENTRATIONS
 BAG             1       AIR(1)      2      AIR(2)      3       AIR(3)

CO,PPM       800.00       5.00     4.00     1.00    115.50      2.00
HC,PPM C6     49.00       1.06     2.80     1.08      6.60      0.94
NOX,PPM       61.00       0.17    30.00     0.21     55.50      0.25
CO2,PCT        1.85       0.04     1.15     0.04      1.65      0.04

PUMP REV     9540.               16380.              9530.
TEMP            122. F
PUMP CAPACITY     0.3170 CF/REV



                   RESULTS
BAG            1           2           3

VMIX        2722.       4674.       2719.
DF             6.83       11.62        8.02

            MASS EMISSIONS, GRAMS/BAG

CO          67.74        0.45        9.71
HC          12.82        0.83        1.53
NOX          8.97        7.54        8.14
CO2       2571.58     2700.91     2282.83
CARBON     741.93      737.97      628.46

FUEL
LBS/BAG       1.88        1.87        1.59

                                        INDOLENE MILEAGE
AVERAGE COLD START MILEAGE         12.31 MILES/GAL       5.237 KM/LITRE
AVERAGE HOT START MILEAGE          13.34                 5.672
OVERALL TEST MILEAGE               12.68                 5.392
WEIGHTED TEST MILEAGE              12.88                 5.477


                     WEIGHTED MASS EMISSIONS

               CO        4.682 G/MILE        2.909 G/KM
               HC        0.963               0.598
               NOX       2.139               1.329
     CORRECTED NOX       2.052               1.275
               CO2     681.054             423.187
```

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DATE 4 29 77                        VEHICLE NO. 26                   MAKE NOVA
STAND 2                             ODOMETER 18356
FUEL INDOLENE

WET BULB TEMP     56                ABSOLUTE HUMIDITY   48.0 GRNS/LBS DRY AIR
DRY BULB TEMP     68                RELATIVE HUMIDITY   47.0 PCT
BAROMETRIC PRES. 767.               PUMP INLET PRES.     6.90 INCHES OF H2O

                              MEASURED CONCENTRATIONS
 BAG              1        AIR(1)      2       AIR(2)      3        AIR(3)

CO,PPM        939.00        5.00      7.00      2.00    215.00      10.50
HC,PPM C6      58.00        0.88      2.40      0.72      8.00       0.56
NOX,PPM        62.00        0.14     28.00      0.13     52.00       0.15
CO2,PCT         1.81        0.04      1.27      0.03      1.62       0.04

PUMP REV      9790.                 16380.               9570.
TEMP            123. F
PUMP CAPACITY    0.3170 CF/REV


                       RESULTS
BAG            1            2            3

VMIX        2788.        4666.        2726.
DF             6.91        10.46         8.11

           MASS EMISSIONS, GRAMS/BAG

CO            81.62         0.75        17.61
HC            15.64         0.79         2.00
NOX            9.34         7.04         7.65
CO2         2573.61      3015.40      2247.41
CARBON       750.87       823.89       622.59

FUEL
LBS/BAG      1.90          2.09          1.58

                                       INDOLENE MILEAGE
AVERAGE COLD START MILEAGE          11.57 MILES/GAL       4.922 KM/LITRE
AVERAGE HOT START MILEAGE           12.60                 5.358
OVERALL TEST MILEAGE                12.16                 5.173
WEIGHTED TEST MILEAGE               12.14                 5.161

                          WEIGHTED MASS EMISSIONS

                    CO       6.119 G/MILE         3.802 G/KM
                    HC       1.155                0.718
                    NOX      2.057                1.278
          CORRECTED NOX      1.825                1.134
                    CO2    720.410              447.642
```

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DATE 5 2 77                    VEHICLE NO. 26                 MAKE NOVA
STAND 2                        ODOMETER 18377
FUEL INDOLENE


WET BULB TEMP     65           ABSOLUTE HUMIDITY   82.0 GRNS/LBS DRY AIR
DRY BULB TEMP     72           RELATIVE HUMIDITY   69.0 PCT
BAROMETRIC PRES. 767.          PUMP INLET PRES.     7.00 INCHES OF H2O


                          MEASURED CONCENTRATIONS
 BAG             1       AIR(1)      2       AIR(2)      3       AIR(3)

CO,PPM     1200.00        6.00     31.00      5.00    366.00      6.00
HC,PPM C6    31.00        1.26      3.20      1.30      8.00      1.30
NOX,PPM      48.50        0.25     28.00      0.24     40.00      0.27
CO2,PCT       2.07        0.04      1.44      0.04      1.85      0.04

PUMP REV     9590.                 16380.              9580.
TEMP             128. F
PUMP CAPACITY    0.3160 CF/REV



                      RESULTS
BAG            1            2            3

VMIX        2699.        4610.        2696.
DF            6.06         9.26         7.06

          MASS EMISSIONS, GRAMS/BAG

CO           99.71         3.81        30.20
HC            7.92         0.92         1.81
NOX           7.06         6.93         5.80
CO2        2857.30      3351.37      2542.45
CARBON      829.35       916.99       708.34

FUEL
LBS/BAG       2.10         2.33         1.80

                                    INDOLENE MILEAGE
AVERAGE COLD START MILEAGE        10.44 MILES/GAL       4.438 KM/LITRE
AVERAGE HOT START MILEAGE         11.21                 4.768
OVERALL TEST MILEAGE              10.89                 4.631
WEIGHTED TEST MILEAGE             10.86                 4.621

                     WEIGHTED MASS EMISSIONS

           CO        8.520 G/MILE       5.294 G/KM
           HC        0.715              0.444
           NOX       1.771              1.100
 CORRECTED NOX       1.831              1.138
           CO2     803.895            499.517
```

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                                    VEHICLE NO. 26             MAKE NOVA
DATE 5 5 77                         ODOMETER 18448.8
STAND 2
FUEL K90

                                    ABSOLUTE HUMIDITY   75.0 GRNS/LBS DRY AIR
WET BULB TEMP     63                RELATIVE HUMIDITY   68.0 PCT
DRY BULB TEMP     70                PUMP INLET PRES.     6.90 INCHES OF H2O
BAROMETRIC PRES. 758.


                          MEASURED CONCENTRATIONS
BAG              1       AIR(1)      2      AIR(2)      3        AIR(3)

CO,PPM       1150.00      6.00     16.00     14.00    210.00      7.87
HC,PPM C6      25.00      1.10      3.40      1.60      7.00      1.48
NOX,PPM        50.00      0.30     27.50      0.28     48.50      0.45
CO2,PCT         1.90      0.04      1.26      0.04      1.65      0.04

PUMP REV      9600.               16380.               9570.
TEMP             120. F
PUMP CAPACITY     0.3170 CF/REV


                      RESULTS
BAG            1          2          3

VMIX        2716.       4634.      2707.
DF             6.59       10.57       7.97

              MASS EMISSIONS, GRAMS/BAG

CO            96.49        0.43      17.13
HC             6.40        0.88       1.51
NOX            7.31        6.83       7.05
CO2         2633.24     2939.35    2269.58
CARBON       765.51      803.08     628.01

FUEL
LBS/BAG       1.94        2.04        1.59
                                   INDOLENE MILEAGE
AVERAGE COLD START MILEAGE       11.62 MILES/GAL       4.941 KM/LITRE
AVERAGE HOT START MILEAGE        12.73                 5.416
OVERALL TEST MILEAGE             12.17                 5.175
WEIGHTED TEST MILEAGE            12.23                 5.201


                      WEIGHTED MASS EMISSIONS

               CO        6.892 G/MILE         4.282 G/KM
               HC        0.600                0.373
               NOX       1.867                1.160
     CORRECTED NOX       1.867                1.160
               CO2     715.374              444.512
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DATE 5 6 77                          VEHICLE NO. 26              MAKE NOVA
STAND 2                              ODOMETER 18475.4
FUEL K-90


WET BULB TEMP     70                 ABSOLUTE HUMIDITY  101.0 GRNS/LBS DRY AIR
DRY BULB TEMP     76                 RELATIVE HUMIDITY   74.0 PCT
BAROMETRIC PRES. 757.                PUMP INLET PRES.     6.90 INCHES OF H2O


                                MEASURED CONCENTRATIONS
 BAG               1        AIR(1)      2        AIR(2)      3        AIR(3)

CO,PPM        647.50        3.00     14.00        8.75    193.75        8.75
HC,PPM C6      25.00        2.20      4.40        2.60      7.30        2.20
NOX,PPM        49.00        0.40     28.00        0.33     46.50        0.35
CO2,PCT         1.98        0.05      1.40        0.05      1.69        0.04

PUMP REV      9570.                 16390.                 9560.
TEMP              120. F
PUMP CAPACITY      0.3170 CF/REV



                           RESULTS
BAG             1              2            3

VMIX        2703.          4630.        2701.
DF             6.50           9.54         7.79

            MASS EMISSIONS, GRAMS/BAG

CO            53.92           0.86        15.61
HC             6.13           0.94         1.42
NOX            7.12           6.94         6.75
CO2         2720.83        3254.10      2322.19
CARBON       770.92         889.20       641.63

FUEL
LBS/BAG        1.96           2.26         1.63

                                      INDOLENE MILEAGE
AVERAGE COLD START MILEAGE         10.98 MILES/GAL       4.669 KM/LITRE
AVERAGE HOT START MILEAGE          11.90                 5.063
OVERALL TEST MILEAGE               11.61                 4.939
WEIGHTED TEST MILEAGE              11.49                 4.885


                          WEIGHTED MASS EMISSIONS

                CO        4.393 G/MILE          2.729 G/KM
                HC        0.585                 0.363
                NOX       1.848                 1.148
      CORRECTED NOX       2.106                 1.308
                CO2     766.362               476.195
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DATE 5 9 77                  VEHICLE NO. 26                 MAKE NOVA
STAND 2                      ODOMETER 18581.2
FUEL K-90


WET BULB TEMP    57          ABSOLUTE HUMIDITY   53.5 GRNS/LBS DRY AIR
DRY BULB TEMP    67          RELATIVE HUMIDITY   53.5 PCT
BAROMETRIC PRES. 749.        PUMP INLET PRES.      6.80 INCHES OF H2O


                        MEASURED CONCENTRATIONS
 BAG           1      AIR(1)     2      AIR(2)     3      AIR(3)

CO,PPM      907.50     6.00     6.00     3.00   153.00     5.00
HC,PPM C6    31.00     1.20     3.30     1.62     5.60     1.28
NOX,PPM      60.00     0.33    30.00     0.15    56.00     0.17
CO2,PCT       1.90     0.05     1.31     0.04     1.59     0.04

PUMP REV     9610.            16370.            9600.
TEMP           120. F
PUMP CAPACITY    0.3175 CF/REV


                   RESULTS
BAG         1           2           3

VMIX      2690.       4583.       2688.
DF         6.65       10.18        8.32

           MASS EMISSIONS, GRAMS/BAG

CO        75.72        0.46       12.52
HC         7.90        0.82        1.17
NOX        8.70        7.41        8.13
CO2     2602.90     3023.04     2162.38
CARBON   749.62      825.88      596.49

FUEL
LBS/BAG     1.90        2.10        1.51

                                   INDOLENE MILEAGE
AVERAGE COLD START MILEAGE      11.57 MILES/GAL     4.919 KM/LITRE
AVERAGE HOT START MILEAGE       12.81               5.449
OVERALL TEST MILEAGE            12.31               5.234
WEIGHTED TEST MILEAGE           12.25               5.208


                    WEIGHTED MASS EMISSIONS

            CO       5.355 G/MILE       3.327 G/KM
            HC       0.652              0.405
            NOX      2.105              1.308
  CORRECTED NOX      1.912              1.188
            CO2    716.646            445.303
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DATE 5 10 77                      VEHICLE NO. 26                  MAKE NOVA
STAND 2                           ODOMETER 18665.5
FUEL K 90


WET BULB TEMP     58              ABSOLUTE HUMIDITY   56.0 GRNS/LBS DRY AIR
DRY BULB TEMP     68              RELATIVE HUMIDITY   54.0 PCT
BAROMETRIC PRES. 754.             PUMP INLET PRES.     6.90 INCHES OF H2O



                              MEASURED CONCENTRATIONS
 BAG              1       AIR(1)      2       AIR(2)      3       AIR(3)

CO,PPM        565.00       2.00      6.00      2.00     58.62      6.00
HC,PPM C6      22.00       1.15      3.00      1.16      5.60      1.18
NOX,PPM        61.50       0.15     32.50      0.15     59.00      0.22
CO2,PCT         1.87       0.04      1.37      0.04      1.66      0.04

PUMP REV     9630.              16380.               9590.
TEMP            120. F
PUMP CAPACITY     0.3175 CF/REV



                       RESULTS
BAG            1            2             3

VMIX        2714.        4616.         2702.
DF             6.90         9.72          7.99

            MASS EMISSIONS, GRAMS/BAG

CO            47.70         0.60          4.50
HC             5.58         0.88          1.20
NOX            9.02         8.09          8.60
CO2         2590.58      3205.51       2281.78
CARBON       732.24       875.78        625.66

FUEL
LBS/BAG        1.86         2.22          1.59

                                            INDOLENE MILEAGE
AVERAGE COLD START MILEAGE           11.33 MILES/GAL      4.820 KM/LITRE
AVERAGE HOT START MILEAGE            12.14                5.162
OVERALL TEST MILEAGE                 11.97                5.089
WEIGHTED TEST MILEAGE                11.78                5.009


                             WEIGHTED MASS EMISSIONS

                CO        3.158 G/MILE         1.962 G/KM
                HC        0.530                0.329
                NOX       2.250                1.398
      CORRECTED NOX       2.066                1.283
                CO2     749.343              465.620
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DATE 5 11 77                        VEHICLE NO. 26                  MAKE NOVA
STAND 2                             ODOMETER 18723.0
FUEL K 90


WET BULB TEMP     59                ABSOLUTE HUMIDITY   56.5 GRNS/LBS DRY AIR
DRY BULB TEMP     70                RELATIVE HUMIDITY   51.0 PCT
BAROMETRIC PRES. 761.               PUMP INLET PRES.     6.95 INCHES OF H2O


                              MEASURED CONCENTRATIONS
 BAG             1       AIR(1)       2       AIR(2)       3       AIR(3)

CO,PPM        540.00       5.00       7.00      5.00      46.00      3.00
HC,PPM C6      19.60       1.39       2.80      1.34       4.80      1.16
NOX,PPM        61.00       0.23      32.00      0.15      60.50      0.15
CO2,PCT         1.87       0.03       1.29      0.04       1.59      0.04

PUMP REV      9560.                 16380.                9600.
TEMP             120. F
PUMP CAPACITY     0.3175 CF/REV



                          RESULTS
BAG              1             2             3

VMIX          2719.         4659.         2730.
DF              6.91          10.32          8.38

              MASS EMISSIONS, GRAMS/BAG

CO             45.49          0.34          3.71
HC              4.90          0.72          1.01
NOX             8.95          8.04          8.92
CO2          2602.34       3042.24       2202.98
CARBON        733.91        830.98        603.64

FUEL
LBS/BAG        1.86          2.11          1.53

                                        INDOLENE MILEAGE
AVERAGE COLD START MILEAGE        11.65 MILES/GAL        4.953 KM/LITRE
AVERAGE HOT START MILEAGE         12.70                  5.402
OVERALL TEST MILEAGE              12.33                  5.242
WEIGHTED TEST MILEAGE             12.23                  5.199


                       WEIGHTED MASS EMISSIONS

                   CO         2.937 G/MILE          1.825 G/KM
                   HC         0.454                 0.282
                   NOX        2.264                 1.406
         CORRECTED NOX        2.083                 1.294
                   CO2      722.260               448.792
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DATE 5 13 77                       VEHICLE NO. 26                 MAKE NOVA
STAND 2                            ODOMETER 18774.4
FUEL K 90


WET BULB TEMP     63               ABSOLUTE HUMIDITY   71.5 GRNS/LBS DRY AIR
DRY BULB TEMP     72               RELATIVE HUMIDITY   61.0 PCT
BAROMETRIC PRES. 755.              PUMP INLET PRES.     6.90 INCHES OF H2O


                             MEASURED CONCENTRATIONS
 BAG              1       AIR(1)       2       AIR(2)       3       AIR(3)

CO,PPM       600.00        2.00      4.00       1.00    180.25       1.00
HC,PPM C6     25.00        1.22      3.20       1.27      7.50       1.28
NOX,PPM       52.00        0.10     26.50       0.12     52.00       0.15
CO2,PCT        1.89        0.04      1.25       0.04      1.62       0.04

PUMP REV      9570.               16370.                 9560.
TEMP             120. F
PUMP CAPACITY     0.3175 CF/REV



                         RESULTS
BAG            1             2             3

VMIX        2700.         4620.         2698.
DF             6.82         10.70          8.13

           MASS EMISSIONS, GRAMS/BAG

CO            50.28          0.44         15.14
HC             6.34          0.92          1.68
NOX            7.59          6.60          7.57
CO2         2601.11       2907.54       2224.25
CARBON       736.88        794.44        614.93

FUEL
LBS/BAG       1.87          2.02          1.56
                                             INDOLENE MILEAGE
AVERAGE COLD START MILEAGE        11.90 MILES/GAL       5.061 KM/LITRE
AVERAGE HOT START MILEAGE         12.93                 5.499
OVERALL TEST MILEAGE              12.45                 5.296
WEIGHTED TEST MILEAGE             12.47                 5.302


                    WEIGHTED MASS EMISSIONS

            CO          4.093 G/MILE          2.543 G/KM
            HC          0.615                 0.382
            NOX         1.891                 1.175
  CORRECTED NOX         1.861                 1.156
            CO2       705.846               438.592
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DATE 6 1 77                         VEHICLE NO. 26              MAKE NOVA
STAND 2                             ODOMETER 19689.1
FUEL K90


WET BULB TEMP     70                ABSOLUTE HUMIDITY  102.0 GRNS/LBS DRY AIR
DRY BULB TEMP     75                RELATIVE HUMIDITY   78.0 PCT
BAROMETRIC PRES. 758.               PUMP INLET PRES.     6.90 INCHES OF H2O


                            MEASURED CONCENTRATIONS
 BAG              1       AIR(1)      2      AIR(2)      3      AIR(3)

CO,PPM        737.50       8.75      8.75     4.00    190.50     6.00
HC,PPM C6      33.00       1.56      4.00     1.60      8.00     1.62
NOX,PPM        35.00       0.30     20.00     0.20     39.00     0.25
CO2,PCT         1.90       0.04      1.26     0.05      1.77     0.04

PUMP REV      9560.                16380.              9550.
TEMP              125. F
PUMP CAPACITY     0.3175 CF/REV



                      RESULTS
BAG            1           2            3

VMIX        2685.        4601.        2683.
DF             6.71        10.57         7.46

           MASS EMISSIONS, GRAMS/BAG

CO            60.62        0.72        15.40
HC             8.33        1.15         1.73
NOX            5.05        4.93         5.63
CO2         2609.72     2908.02      2412.32
CARBON       745.38      794.88       666.41

FUEL
LBS/BAG       1.89        2.02         1.69

                                        INDOLENE MILEAGE
AVERAGE COLD START MILEAGE         11.83 MILES/GAL      5.032 KM/LITRE
AVERAGE HOT START MILEAGE          12.47                5.304
OVERALL TEST MILEAGE               12.11                5.151
WEIGHTED TEST MILEAGE              12.19                5.183


                       WEIGHTED MASS EMISSIONS

                CO         4.743 G/MILE        2.947 G/KM
                HC         0.763               0.474
                NOX        1.376               0.855
      CORRECTED NOX        1.576               0.979
                CO2      720.697             447.820
```

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DATE 8 25 77                      VEHICLE NO. 26                MAKE NOVA
STAND 3                           ODOMETER 21,638
FUEL INDOLENE


WET BULB TEMP     62.5            ABSOLUTE HUMIDITY   72.0 GRNS/LBS DRY AIR
DRY BULB TEMP     70              RELATIVE HUMIDITY   65.0 PCT
BAROMETRIC PRES. 767.             PUMP INLET PRES.    10.70 INCHES OF H2O


                           MEASURED CONCENTRATIONS
 BAG               1        AIR(1)      2      AIR(2)      3       AIR(3)

CO,PPM       977.50        6.00     17.00       1.00   301.30      3.00
HC,PPM C6     33.00        1.46      4.00       1.00    10.50      1.10
NOX,PPM       34.50        0.23     16.50       0.22    28.50      0.16
CO2,PCT        2.17        0.05      1.50       0.05     1.89      0.04

PUMP REV      8250.             14120.               8290.
TEMP             70. F
PUMP CAPACITY     0.3150 CF/REV



                     RESULTS
BAG            1            2            3

VMIX        2544.        4355.        2557.
DF            5.86         8.90         6.95

           MASS EMISSIONS, GRAMS/BAG

CO           76.44         2.19        23.73
HC            7.92         1.32         2.39
NOX           4.72         3.84         3.92
CO2        2815.02      3287.07      2463.04
CARBON      807.84       899.11       684.39

FUEL
LBS/BAG       2.05         2.28         1.74

                                        INDOLENE MILEAGE
AVERAGE COLD START MILEAGE        10.68 MILES/GAL      4.540 KM/LITRE
AVERAGE HOT START MILEAGE         11.51                4.894
OVERALL TEST MILEAGE              11.18                4.753
WEIGHTED TEST MILEAGE             11.14                4.736


                       WEIGHTED MASS EMISSIONS

             CO        6.479 G/MILE          4.025 G/KM
             HC        0.813                 0.505
             NOX       1.082                 0.672
   CORRECTED NOX       1.067                 0.663
             CO2     786.862               488.933
```

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DATE 8 30 77                   VEHICLE NO. 26             MAKE NOVA
STAND 2                        ODOMETER 21,765
FUEL INDOLENE


WET BULB TEMP     74           ABSOLUTE HUMIDITY  118.0 GRNS/LBS DRY AIR
DRY BULB TEMP     80           RELATIVE HUMIDITY   76.0 PCT
BAROMETRIC PRES. 766.          PUMP INLET PRES.     6.85 INCHES OF H2O


                              MEASURED CONCENTRATIONS
 BAG               1       AIR(1)      2      AIR(2)       3       AIR(3)

CO,PPM        745.00        5.00    46.00      4.00    438.80       4.00
HC,PPM C6      31.00        2.70     5.50      2.90     37.00       2.70
NOX,PPM        32.50        0.24    16.80      0.18     31.00       0.34
CO2,PCT         2.05        0.04     1.38      0.04      1.90       0.05

PUMP REV     9550.                 16380.               9650.
TEMP             130. F
PUMP CAPACITY     0.3160 CF/REV


                       RESULTS
BAG             1             2             3

VMIX        2676.         4590.         2704.
DF           6.24          9.60          6.79

                MASS EMISSIONS, GRAMS/BAG

CO          61.16          6.07         36.43
HC           7.53          1.30          9.19
NOX          4.68          4.13          4.49
CO2       2803.59       3207.88       2615.80
CARBON     797.83        879.14        737.42

FUEL
LBS/BAG      2.02          2.23          1.87

                                  INDOLENE MILEAGE
AVERAGE COLD START MILEAGE      10.87 MILES/GAL      4.622 KM/LITRE
AVERAGE HOT START MILEAGE       11.27                4.794
OVERALL TEST MILEAGE            11.07                4.708
WEIGHTED TEST MILEAGE           11.09                4.719


                       WEIGHTED MASS EMISSIONS

                CO        7.085 G/MILE        4.402 G/KM
                HC        1.304               0.810
                NOX       1.161               0.721
      CORRECTED NOX       1.456               0.904
                CO2     787.257             489.179
```

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DATE 8 31 77                      VEHICLE NO. 26                 MAKE NOVA
STAND 2                           ODOMETER 21,803
FUEL INDOLENE


WET BULB TEMP      74             ABSOLUTE HUMIDITY  117.0 GRNS/LBS DRY AIR
DRY BULB TEMP      80             RELATIVE HUMIDITY   76.0 PCT
BAROMETRIC PRES. 769.             PUMP INLET PRES.     6.90 INCHES OF H2O


                              MEASURED CONCENTRATIONS
 BAG              1       AIR(1)      2       AIR(2)      3       AIR(3)

CO,PPM       552.50        3.00    12.50       2.00    212.50      5.00
HC,PPM C6     29.00        2.00     5.80       2.10     10.10      2.10
NOX,PPM       50.00        0.23    28.50       0.25     49.50      0.19
CO2,PCT        1.95        0.04     1.42       0.04      1.80      0.04

PUMP REV     10010.               16400.                9570.
TEMP             130. F
PUMP CAPACITY      0.3170 CF/REV



                      RESULTS
BAG            1             2            3

VMIX        2825.          4628.        2700.
DF            6.63           9.36         7.33

                MASS EMISSIONS, GRAMS/BAG

CO           48.03           1.54        17.42
HC            7.55           1.77         2.19
NOX           7.62           7.08         7.21
CO2        2800.48        3325.87      2466.40
CARBON      791.37         909.81       682.43

FUEL
LBS/BAG      2.01           2.31          1.73

                                         INDOLENE MILEAGE
AVERAGE COLD START MILEAGE         10.71 MILES/GAL       4.556 KM/LITRE
AVERAGE HOT START MILEAGE          11.45                 4.868
OVERALL TEST MILEAGE               11.21                 4.769
WEIGHTED TEST MILEAGE              11.12                 4.728

                         WEIGHTED MASS EMISSIONS

                CO         4.284 G/MILE          2.662 G/KM
                HC         0.837                 0.520
                NOX        1.930                 1.199
      CORRECTED NOX        2.405                 1.494
                CO2      791.457               491.788
```

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DATE 9 1 77                                 VEHICLE NO. 26                      MAKE NOVA
STAND 2                                     ODOMETER 21,886
FUEL INDOLENE


WET BULB TEMP      74                       ABSOLUTE HUMIDITY  119.0 GRNS/LBS DRY AIR
DRY BULB TEMP      79                       RELATIVE HUMIDITY   79.0 PCT
BAROMETRIC PRES. 769.                       PUMP INLET PRES.     6.85 INCHES OF H2O


                                     MEASURED CONCENTRATIONS
 BAG                  1         AIR(1)      2        AIR(2)       3        AIR(3)

CO,PPM           533.80         3.00       6.00       2.00     136.00       1.00
HC,PPM C6         22.00         2.60       4.90       2.50      19.40       2.40
NOX,PPM           59.50         0.27      29.00       0.18      57.00       0.23
CO2,PCT            1.90         0.04       1.27       0.04       1.72       0.04

PUMP REV        9550.                  16380.                  9590.
TEMP                130. F
PUMP CAPACITY        0.3170 CF/REV


                              RESULTS
BAG              1               2             3

VMIX          2695.          4623.         2706.
DF               6.79          10.45          7.65

                 MASS EMISSIONS, GRAMS/BAG

CO              44.26           0.60         11.34
HC               5.22           1.19          4.59
NOX              8.65           7.22          8.32
CO2           2613.18        2977.06       2375.15
CARBON         736.62         813.71        657.00

FUEL
LBS/BAG          1.87           2.06          1.67

                                            INDOLENE MILEAGE
AVERAGE COLD START MILEAGE             11.75 MILES/GAL        4.999 KM/LITRE
AVERAGE HOT START MILEAGE              12.39                  5.270
OVERALL TEST MILEAGE                   12.11                  5.150
WEIGHTED TEST MILEAGE                  12.11                  5.150


                             WEIGHTED MASS EMISSIONS

                 CO         3.480 G/MILE           2.162 G/KM
                 HC         0.807                  0.502
                 NOX        2.091                  1.299
       CORRECTED NOX        2.637                  1.638
                 CO2      727.276                451.908
```

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DATE 9 6 77                   VEHICLE NO. 26              MAKE NOVA
STAND 2                       ODOMETER 21,947
FUEL INDOLENE


WET BULB TEMP     72          ABSOLUTE HUMIDITY  112.0 GRNS/LBS DRY AIR
DRY BULB TEMP     76          RELATIVE HUMIDITY   83.0 PCT
BAROMETRIC PRES. 762.         PUMP INLET PRES.     6.90 INCHES OF H2O


                         MEASURED CONCENTRATIONS
 BAG             1       AIR(1)      2       AIR(2)      3       AIR(3)

CO,PPM       860.00       5.00      9.50      2.00    200.00      3.00
HC,PPM C6     33.00       1.50      5.00      1.18      9.80      1.08
NOX,PPM       42.50       0.23     21.50      0.25     43.00      0.27
CO2,PCT        1.96       0.04      1.40      0.04      1.80      0.04

PUMP REV      9590.               16360.               9550.
TEMP             125. F
PUMP CAPACITY    0.3170 CF/REV


                     RESULTS
BAG            1           2           3

VMIX        2704.       4613.       2693.
DF          6.48        9.54        7.34

               MASS EMISSIONS, GRAMS/BAG

CO          71.35        1.10       16.44
HC           8.40        1.78        2.33
NOX          6.19        5.31        6.23
CO2       2703.51     3252.73     2459.29
CARBON     775.65      889.66      680.20

FUEL
LBS/BAG      1.97        2.26        1.73

                                  INDOLENE MILEAGE
AVERAGE COLD START MILEAGE       10.94 MILES/GAL      4.654 KM/LITRE
AVERAGE HOT START MILEAGE        11.61                4.937
OVERALL TEST MILEAGE             11.40                4.846
WEIGHTED TEST MILEAGE            11.31                4.811

                     WEIGHTED MASS EMISSIONS

               CO        5.487 G/MILE        3.410 G/KM
               HC        0.897               0.557
               NOX       1.538               0.955
     CORRECTED NOX       1.862               1.157
               CO2     775.605             481.938
```

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DATE 9 7 77                        VEHICLE NO. 26               MAKE NOVA
STAND 2                            ODOMETER 21,976
FUEL INDOLENE


WET BULB TEMP     63               ABSOLUTE HUMIDITY   72.0 GRNS/LBS DRY AIR
DRY BULB TEMP     72               RELATIVE HUMIDITY   62.0 PCT
BAROMETRIC PRES. 766.              PUMP INLET PRES.     6.95 INCHES OF H2O



                              MEASURED CONCENTRATIONS
 BAG              1       AIR(1)      2      AIR(2)      3       AIR(3)

CO,PPM     1770.00        7.00     10.50      2.00    200.00      1.00
HC,PPM C6   194.00        1.12      4.30      0.96     15.60      0.84
NOX,PPM      51.00        0.19     27.50      0.17     52.50      0.25
CO2,PCT       1.95        0.04      1.42      0.04      1.80      0.04

PUMP REV     9600.               16380.              9560.
TEMP             125. F
PUMP CAPACITY     0.3170 CF/REV



                         RESULTS
BAG           1            2            3

VMIX        2721.        4643.        2710.
DF           6.00         9.37         7.32

           MASS EMISSIONS, GRAMS/BAG

CO        149.15         1.26        16.81
HC         51.48         1.56         3.94
NOX         7.49         6.87         7.67
CO2      2704.54      3347.25      2480.79
CARBON    846.61       915.33       687.62

FUEL
LBS/BAG     2.15         2.32         1.74

                                    INDOLENE MILEAGE
AVERAGE COLD START MILEAGE        10.34 MILES/GAL      4.399 KM/LITRE
AVERAGE HOT START MILEAGE         11.37                4.835
OVERALL TEST MILEAGE              10.91                4.640
WEIGHTED TEST MILEAGE             10.90                4.637


                         WEIGHTED MASS EMISSIONS

            CO         9.998 G/MILE         6.212 G/KM
            HC         3.460                2.150
            NOX        1.929                1.199
  CORRECTED NOX        1.903                1.182
            CO2      789.901              490.821
```

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DATE 9 8 77                 VEHICLE NO. 26                 MAKE NOVA
STAND 2                     ODOMETER 22,039
FUEL INDOLENE


WET BULB TEMP     68        ABSOLUTE HUMIDITY   88.0 GRNS/LBS DRY AIR
DRY BULB TEMP     77        RELATIVE HUMIDITY   64.0 PCT
BAROMETRIC PRES. 767.       PUMP INLET PRES.     7.00 INCHES OF H2O



                        MEASURED CONCENTRATIONS
 BAG             1      AIR(1)      2      AIR(2)      3      AIR(3)

CO,PPM       915.00      5.00      7.00     2.00    123.00     1.00
HC,PPM C6     40.00      1.18      3.80     1.16      7.60     1.44
NOX,PPM       55.00      0.20     29.50     0.19     51.50     0.17
CO2,PCT        1.98      0.04      1.40     0.03      1.77     0.03

PUMP REV     9590.              16390.              9560.
TEMP             125. F
PUMP CAPACITY    0.3170 CF/REV



                  RESULTS
BAG           1           2           3

VMIX       2721.       4651.       2713.
DF          6.40        9.55        7.48

           MASS EMISSIONS, GRAMS/BAG

CO         76.90        0.75       10.32
HC         10.40        1.25        1.68
NOX         8.08        7.38        7.54
CO2      2750.96     3301.22     2451.72
CARBON    792.70      902.29      674.94

FUEL
LBS/BAG      2.01        2.29        1.71

                                    INDOLENE MILEAGE
AVERAGE COLD START MILEAGE      10.75 MILES/GAL     4.572 KM/LITRE
AVERAGE HOT START MILEAGE       11.55               4.914
OVERALL TEST MILEAGE            11.28               4.796
WEIGHTED TEST MILEAGE           11.19               4.761


                  WEIGHTED MASS EMISSIONS

            CO        5.294 G/MILE        3.289 G/KM
            HC        0.892               0.554
            NOX       2.022               1.256
  CORRECTED NOX       2.153               1.338
            CO2     784.215             487.289
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DATE 9 9 77                    VEHICLE NO. 26                MAKE NOVA
STAND 2                        ODOMETER 22,088
FUEL INDOLENE


WET BULB TEMP     66           ABSOLUTE HUMIDITY   80.0 GRNS/LBS DRY AIR
DRY BULB TEMP     76           RELATIVE HUMIDITY   58.0 PCT
BAROMETRIC PRES. 767.          PUMP INLET PRES.     6.90 INCHES OF H2O


                          MEASURED CONCENTRATIONS
 BAG             1       AIR(1)      2      AIR(2)      3       AIR(3)

CO,PPM       730.00       5.00      9.60     5.00     70.80      5.00
HC,PPM C6     26.00       1.06      4.00     1.33      8.80      1.41
NOX,PPM       55.50       0.25     28.00     0.20     55.50      0.35
CO2,PCT        2.00       0.05      1.40     0.04      1.80      0.04

PUMP REV     9590.              16380.               9610.
TEMP            125. F
PUMP CAPACITY    0.3170 CF/REV



                      RESULTS
BAG            1          2          3

VMIX       2722.      4650.      2728.
DF          6.41       9.54       7.39

           MASS EMISSIONS, GRAMS/BAG

CO         61.39       0.73       5.64
HC          6.69       1.27       2.02
NOX         8.15       7.00       8.15
CO2      2769.35    3278.44    2491.20
CARBON    787.86     896.08     684.00

FUEL
LBS/BAG     2.00       2.27       1.73

                                  INDOLENE MILEAGE
AVERAGE COLD START MILEAGE      10.82 MILES/GAL      4.603 KM/LITRE
AVERAGE HOT START MILEAGE       11.53                4.905
OVERALL TEST MILEAGE            11.29                4.800
WEIGHTED TEST MILEAGE           11.22                4.770


                      WEIGHTED MASS EMISSIONS

             CO       4.046 G/MILE       2.514 G/KM
             HC       0.708              0.440
             NOX      2.021              1.256
   CORRECTED NOX      2.070              1.286
             CO2    785.233            487.921
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DATE 9 13 77                          VEHICLE NO. 26                MAKE NOVA
STAND 2                               ODOMETER 22,141.3
FUEL INDOLENE


WET BULB TEMP      63                 ABSOLUTE HUMIDITY   75.0 GRNS/LBS DRY AIR
DRY BULB TEMP      70                 RELATIVE HUMIDITY   68.0 PCT
BAROMETRIC PRES. 765.                 PUMP INLET PRES.     6.95 INCHES OF H2O


                               MEASURED CONCENTRATIONS
 BAG                 1       AIR(1)      2        AIR(2)      3        AIR(3)

CO,PPM          948.00        8.80      4.00       1.00     33.00       1.00
HC,PPM C6        26.00        0.82      3.50       1.00      5.60       0.84
NOX,PPM          59.50        0.15     24.50       0.15     57.00       0.15
CO2,PCT           1.98        0.04      1.29       0.04      1.72       0.04

PUMP REV        9600.                16290.                 9610.
TEMP                 125. F
PUMP CAPACITY      0.3175 CF/REV


                           RESULTS
BAG              1             2             3

VMIX          2722.          4619.         2724.
DF               6.41          10.34          7.73

                MASS EMISSIONS, GRAMS/BAG

CO              79.31           0.44          2.72
HC               6.74           1.17          1.29
NOX              8.75           6.09          8.39
CO2           2745.21        3010.19       2390.84
CARBON         789.00         822.66        654.73

FUEL
LBS/BAG          2.00           2.09          1.66

                                            INDOLENE MILEAGE
AVERAGE COLD START MILEAGE           11.31 MILES/GAL        4.809 KM/LITRE
AVERAGE HOT START MILEAGE            12.34                  5.246
OVERALL TEST MILEAGE                 11.79                  5.016
WEIGHTED TEST MILEAGE                11.87                  5.049


                          WEIGHTED MASS EMISSIONS

                 CO         4.813 G/MILE         2.991 G/KM
                 HC         0.642                0.399
                 NOX        1.952                1.213
       CORRECTED NOX        1.952                1.213
                 CO2      740.455              460.097
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DATE 9 16 77                            VEHICLE NO. 26                  MAKE NOVA
STAND 2                                 ODOMETER 22435.7
FUEL INDOLENE TK.90


WET BULB TEMP     66.0                  ABSOLUTE HUMIDITY   86.0 GRNS/LBS DRY AIR
DRY BULB TEMP     72.0                  RELATIVE HUMIDITY   74.0 PCT
BAROMETRIC PRES. 772.                   PUMP INLET PRES.     6.95 INCHES OF H2O


                               MEASURED CONCENTRATIONS
 BAG              1       AIR(1)      2       AIR(2)      3      AIR(3)

CO,PPM        830.00      1.00     16.00      1.00    168.50      1.00
HC,PPM C6      44.00      2.00      4.20      1.30      8.00      1.10
NOX,PPM        46.00      0.11     23.20      0.12     47.00      0.17
CO2,PCT         2.02      0.04      1.37      0.03      1.77      0.04

PUMP REV      9560.               16390.              9550.
TEMP              130. F
PUMP CAPACITY     0.3170 CF/REV



                       RESULTS
BAG             1            2            3

VMIX         2708.        4643.        2705.
DF              6.29         9.71         7.47

           MASS EMISSIONS, GRAMS/BAG

CO             69.38         2.19        14.08
HC             11.23         1.38         1.86
NOX             6.73         5.80         6.86
CO2          2796.62      3237.17      2438.75
CARBON        802.65       885.53       673.17

FUEL
LBS/BAG         2.04         2.25         1.71

                                           INDOLENE MILEAGE
AVERAGE COLD START MILEAGE          10.79 MILES/GAL       4.591 KM/LITRE
AVERAGE HOT START MILEAGE           11.69                 4.972
OVERALL TEST MILEAGE                11.32                 4.814
WEIGHTED TEST MILEAGE               11.29                 4.801


                        WEIGHTED MASS EMISSIONS

                CO        5.340 G/MILE          3.318 G/KM
                HC        0.969                 0.602
                NOX       1.682                 1.045
      CORRECTED NOX       1.773                 1.102
                CO2     777.308               482.996
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DATE 9 19 77                              VEHICLE NO. 26               MAKE NOVA
STAND 2                                   ODOMETER 22,459
FUEL INDOLENE


WET BULB TEMP     71                      ABSOLUTE HUMIDITY  103.0 GRNS/LBS DRY AIR
DRY BULB TEMP     78                      RELATIVE HUMIDITY   72.0 PCT
BAROMETRIC PRES. 757.                     PUMP INLET PRES.     6.85 INCHES OF H2O


                                 MEASURED CONCENTRATIONS
 BAG                  1        AIR(1)       2       AIR(2)       3       AIR(3)

CO,PPM          907.50         6.00       7.00       4.00    232.50       3.00
HC,PPM C6        23.00         2.00       5.20       2.10      8.90       1.66
NOX,PPM          51.50         0.30      21.80       0.29     45.00       0.32
CO2,PCT           2.31         0.04       1.37       0.03      1.81       0.04

PUMP REV      9600.                    16380.                9550.
TEMP              130. F
PUMP CAPACITY     0.3160 CF/REV


                         RESULTS
BAG             1            2            3

VMIX        2658.        4535.        2644.
DF             5.55         9.71         7.25

            MASS EMISSIONS, GRAMS/BAG

CO            73.72         0.47        18.87
HC             5.56         1.47         1.93
NOX            7.37         5.29         6.40
CO2         3142.95      3159.94      2440.99
CARBON       894.12       863.80       675.89

FUEL
LBS/BAG        2.27         2.19         1.71

                                          INDOLENE MILEAGE
AVERAGE COLD START MILEAGE           10.37 MILES/GAL       4.409 KM/LITRE
AVERAGE HOT START MILEAGE            11.84                 5.034
OVERALL TEST MILEAGE                 10.98                 4.671
WEIGHTED TEST MILEAGE                11.16                 4.745


                         WEIGHTED MASS EMISSIONS

                 CO        5.723 G/MILE        3.556 G/KM
                 HC        0.662               0.411
                 NOX       1.615               1.003
       CORRECTED NOX       1.860               1.155
                 CO2     787.037             489.042
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DATE 9 27 77                    VEHICLE NO. 26                MAKE NOVA
STAND 2                         ODOMETER 22,613
FUEL INDOLENE


WET BULB TEMP     62.5          ABSOLUTE HUMIDITY   72.0 GRNS/LBS DRY AIR
DRY BULB TEMP     70            RELATIVE HUMIDITY   66.0 PCT
BAROMETRIC PRES. 755.           PUMP INLET PRES.     7.05 INCHES OF H2O



                          MEASURED CONCENTRATIONS
 BAG              1       AIR(1)      2       AIR(2)       3       AIR(3)

CO,PPM       587.50       3.00      7.00       2.00     83.50       1.00
HC,PPM C6     34.00       1.20      4.40       1.36      7.80       1.14
NOX,PPM       53.50       0.17     23.80       0.15     59.00       0.22
CO2,PCT        2.05       0.04      1.35       0.04      1.81       0.04

PUMP REV     9550.                16390.                9550.
TEMP             126. F
PUMP CAPACITY     0.3170 CF/REV



                       RESULTS
BAG             1             2             3

VMIX        2662.          4569.         2662.
DF             6.28           9.84          7.33

            MASS EMISSIONS, GRAMS/BAG

CO            48.21           0.73          6.84
HC             8.60           1.42          1.77
NOX            7.69           5.85          8.48
CO2         2794.64        3132.31       2456.54
CARBON       790.76         856.33        674.84

FUEL
LBS/BAG        2.01           2.17          1.71

                                      INDOLENE MILEAGE
AVERAGE COLD START MILEAGE         11.06 MILES/GAL      4.705 KM/LITRE
AVERAGE HOT START MILEAGE          11.90                5.062
OVERALL TEST MILEAGE               11.51                4.896
WEIGHTED TEST MILEAGE              11.53                4.902


                     WEIGHTED MASS EMISSIONS

                CO        3.382 G/MILE          2.102 G/KM
                HC        0.818                 0.508
                NOX       1.866                 1.159
      CORRECTED NOX       1.840                 1.143
                CO2     764.565               475.078
 SAVED
 READY
EXEC (LUNT2)
 MEMBER LUNT2 NOT IN DATASET CLIST
 READY
EXEC (LUNT4)
 DATE 10/20/77                VEHICLE NO. 26                MAKE NOVA
 STAND 2                      ODOMETER 29233.00
 FUEL INDOLENE

 WET BULB TEMP    62.0        ABSOLUTE HUMIDITY   68.0 GRNS/LBS DRY AIR
 DRY BULB TEMP    70.0        RELATIVE HUMIDITY   60.0 PCT
 BAROMETRIC PRES. 758.        PUMP INLET PRES.     6.95 INCHES OF H2O

                         MEASURED CONCENTRATIONS
  BAG           1      AIR(1)     2      AIR(2)     3      AIR(3)

 CO,PPM     1275.00     5.00    45.30     3.00   665.00     4.00
 HC,PPM C6    23.00     1.44     4.40     1.62    10.40     1.84
 NOX,PPM      40.00     0.40    20.00     0.27    34.50     0.30
 CO2,PCT       2.10     0.05     1.31     0.05     1.89     0.04
 SO2,PPM       0.0               0.0               0.0




 ***

 PUMP REV     9550.            16370.             9560.
 TEMP           127.  F
 PUMP CAPACITY    0.3160 CF/REV


                    RESULTS
 BAG         1           2           3

 VMIX      2661.       4561.       2664.
 DF          6.00       10.15        6.83

            MASS EMISSIONS, GRAMS/BAG

 CO       104.81        6.11       54.85
 HC         5.68        1.31        2.30
 NOX        5.72        4.88        4.94
 CO2     2845.64     3009.30     2565.98
 CARBON   826.42      824.97      725:75
 SO2        0.0         0.0         0.0

 FUEL
 LBS/BAG     2.10        2.10        1.85
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***

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                                            INDOLENE MILEAGE
AVERAGE COLD START MILEAGE          11.04 MILES/GAL       4.694 KM/LITRE
AVERAGE HOT START MILEAGE           11.76                 4.998
OVERALL TEST MILEAGE                11.25                 4.782
WEIGHTED TEST MILEAGE               11.44                 4.863


                      WEIGHTED MASS EMISSIONS

                CO       10.992 G/MILE          6.830 G/KM
                HC        0.676                 0.420
                NOX       1.354                 0.841
      CORRECTED NOX       1.311                 0.815
                CO2     759.404               471.872
                SO2       0.0                   0.0
                SO2       0.0                   0.0     UNWEIGHTED
READY
```

```
 SAVED
 READY
EXEC (LUNT4)
 DATE 10/21/77                VEHICLE NO. 26                  MAKE NOVA
 STAND 2                      ODOMETER 29310.
 FUEL INDOLENE

 WET BULB TEMP    62.0        ABSOLUTE HUMIDITY   70.0 GRNS/LBS DRY AIR
 DRY BULB TEMP    70.0        RELATIVE HUMIDITY   64.0 PCT
 BAROMETRIC PRES. 767.        PUMP INLET PRES.     7.10 INCHES OF H2O

                           MEASURED CONCENTRATIONS
  BAG            1       AIR(1)     2      AIR(2)     3       AIR(3)

 CO,PPM      1275.00      7.00     64.00     5.00    823.00     1.00
 HC,PPM C6     22.00      1.26      4.20     1.20     10.80     0.98
 NOX,PPM       44.00      0.25     27.00     0.31     36.50     0.19
 CO2,PCT        2.10      0.05      1.52     0.04      1.88     0.04
 SO2,PPM        0.0                 0.0                0.0

 PUMP REV     9540.               16370.              9560.
 TEMP            127.  F




 ***
 PUMP CAPACITY    0.3160 CF/REV


                    RESULTS
 BAG          1           2           3

 VMIX       2689.       4615.       2695.
 DF           6.00        8.74        6.84

              MASS EMISSIONS, GRAMS/BAG

 CO         105.64        8.59       68.90
 HC           5.52        1.42        2.63
 NOX          6.38        6.68        5.30
 CO2       2875.93     3564.08     2578.21
 CARBON     834.90      977.52      735.40
 SO2          0.0         0.0         0.0

 FUEL
 LBS/BAG      2.12        2.49        1.87

                                  INDOLENE MILEAGE
 AVERAGE COLD START MILEAGE     10.06 MILES/GAL     4.277 KM/LITRE
```

```
***
AVERAGE HOT START MILEAGE        10.64                  4.525
OVERALL TEST MILEAGE             10.50                  4.462
WEIGHTED TEST MILEAGE            10.38                  4.415

                      WEIGHTED MASS EMISSIONS

                CO       12.438 G/MILE        7.729 G/KM
                HC        0.706               0.438
                NOX       1.659               1.031
      CORRECTED NOX       1.621               1.007
                CO2     836.041             519.492
                SO2       0.0                 0.0
                SO2       0.0                 0.0      UNWEIGHTED
```

```
 SAVED
 READY
EXEC (LUNT4)
 DATE 10/25/77                  VEHICLE NO. 26                 MAKE NOVA
 STAND 2                        ODOMETER 31223.
 FUEL INDOLENE

 WET BULB TEMP     63.0         ABSOLUTE HUMIDITY   68.5 GRNS/LBS DRY AIR
 DRY BULB TEMP     74.0         RELATIVE HUMIDITY   54.0 PCT
 BAROMETRIC PRES.  775.         PUMP INLET PRES.     7.15 INCHES OF H2O

                            MEASURED CONCENTRATIONS
  BAG               1       AIR(1)     2       AIR(2)      3       AIR(3)

 CO,PPM        438.80        5.00    43.50      3.00    130.00      1.00
 HC,PPM C6      15.30        1.60     4.20      1.28      8.40      1.20
 NOX,PPM        50.00        0.35    19.30      0.17     43.50      0.25
 CO2,PCT         1.95        0.05     1.34      0.05      1.73      0.04
 SO2,PPM         0.0                  0.0                 0.0

 PUMP REV     9560.                16370.              9550.
 TEMP            124.  F




 ***
 PUMP CAPACITY    0.3170 CF/REV


                   RESULTS
 BAG          1           2           3

 VMIX       2746.       4702.       2743.
 DF           6.70        9.97        7.68

              MASS EMISSIONS, GRAMS/BAG

 CO          37.16        6.04       11.08
 HC           3.75        1.40        1.98
 NOX          7.39        4.88        6.43
 CO2       2721.75     3161.98     2406.70
 CARBON     761.93      866.69      663.24
 SO2          0.0         0.0         0.0

 FUEL
 LBS/BAG      1.94        2.20        1.69

                                     INDOLENE MILEAGE
 AVERAGE COLD START MILEAGE      11.19 MILES/GAL     4.759 KM/LITRE
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***
AVERAGE HOT START MILEAGE        11.92                5.066
OVERALL TEST MILEAGE             11.67                4.960
WEIGHTED TEST MILEAGE            11.60                4.930

                    WEIGHTED MASS EMISSIONS

             CO         3.778 G/MILE        2.348 G/KM
             HC         0.553               0.343
             NOX        1.563               0.971
   CORRECTED NOX        1.516               0.942
             CO2      760.552             472.585
             SO2        0.0                 0.0
             SO2        0.0                 0.0     UNWEIGHTED
READY
```

```
 SAVED
 READY
EXEC (LUNT4)
 DATE 10/26/77                  VEHICLE NO. 2                  MAKE NOVA
 STAND 2                        ODOMETER 31245.
 FUEL INDOLENE

 WET BULB TEMP     65. 0        ABSOLUTE HUMIDITY   81. 0 GRNS/LBS DRY AIR
 DRY BULB TEMP     72. 0        RELATIVE HUMIDITY   68. 0 PCT
 BAROMETRIC PRES.  767.         PUMP INLET PRES.     7. 10 INCHES OF H2O

                            MEASURED CONCENTRATIONS
  BAG             1      AIR(1)      2       AIR(2)      3       AIR(3)

 CO, PPM       612. 50     7. 90    50. 00     8. 80   310. 00     7. 90
 HC, PPM C6     17. 40     2. 20     4. 90     2. 20     9. 80     2. 40
 NOX, PPM       48. 50     0. 57    19. 20     0. 50    35. 50     0. 55
 CO2, PCT        1. 98     0. 06     1. 40     0. 05     1. 77     0. 05
 SO2, PPM        0. 0                0. 0                0. 0

 PUMP REV       9550.              16380.              9560.
 TEMP             125.  F




 ***
 PUMP CAPACITY    0. 3170 CF/REV


                   RESULTS
 BAG          1            2            3

 VMIX       2710.        4648.        2713.
 DF           6. 53        9. 52        7. 41

              MASS EMISSIONS, GRAMS/BAG

 CO          50. 85        6. 11       25. 57
 HC           4. 13        1. 33        2. 05
 NOX          7. 05        4. 72        5. 15
 CO2       2717. 21     3257. 44     2428. 07
 CARBON     766. 86      892. 70      675. 35
 SO2          0 0          0. 0         0. 0

 FUEL
 LBS/BAG      1. 95        2. 27        1. 72

                                INDOLENE MILEAGE
 AVERAGE COLD START MILEAGE     10. 99 MILES/GAL     4. 671 KM/LITRE
```

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***
AVERAGE HOT START MILEAGE       11.63               4.943
OVERALL TEST MILEAGE            11.45               4.869
WEIGHTED TEST MILEAGE           11.34               4.822

                    WEIGHTED MASS EMISSIONS

            CO       5.673 G/MILE       3.525 G/KM
            HC       0.571              0 354
            NOX      1.425              0.885
  CORRECTED NOX      1.466              0.911
            CO2    774.644            481.341
            SO2      0.0                0.0
            SO2      0.0                0.0     UNWEIGHTED
READY
```

```
 SAVED
 READY
EXEC (LUNT4)
 DATE 11/3/77                    VEHICLE NO.  26                    MAKE NOVA
 STAND 2                         ODOMETER 33494.
 FUEL  INDOLENE

 WET BULB TEMP     64. 0         ABSOLUTE HUMIDITY   76. 0 GRNS/LBS DRY AIR
 DRY BULB TEMP     72. 5         RELATIVE HUMIDITY   65. 0 PCT
 BAROMETRIC PRES.  772.          PUMP INLET PRES.     7. 35 INCHES OF H2O

                              MEASURED CONCENTRATIONS
  BAG               1       AIR(1)     2       AIR(2)      3        AIR(3)

 CO, PPM         702. 50     3. 00    67. 50     2. 00    276. 30     2. 00
 HC, PPM C6       52. 00     1. 34     5. 90     0. 98     12. 60     0. 95
 NOX, PPM         51. 00     0. 32    22. 60     0. 26     49. 00     0. 27
 CO2, PCT          2. 02     0. 05     1. 39     0. 05      1. 91     0. 05
 SO2, PPM          0. 0                0. 0                 0. 0

 PUMP REV        9660.               16350.                9550.
 TEMP               125.  F




 ***
 PUMP CAPACITY     0. 3160 CF/REV

                         RESULTS
 BAG            1              2              3

 VMIX        2749.          4653.          2718.
 DF             6. 31          9. 59          6. 90

               MASS EMISSIONS,  GRAMS/BAG

 CO            59. 62          9. 59         23. 18
 HC            13. 70          2. 29          3. 14
 NOX            7. 55          5. 64          7. 18
 CO2         2832. 21       3251. 11       2634. 25
 CARBON       810. 33        893. 30        731. 52
 SO2            0. 0           0. 0           0. 0

 FUEL
 LBS/BAG        2. 06          2. 27          1. 86
                                               INDOLENE MILEAGE
 AVERAGE COLD START MILEAGE       10. 70 MILES/GAL      4. 550 KM/LITRE
```

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***
AVERAGE HOT START MILEAGE         11. 22                  4. 771
OVERALL TEST MILEAGE              10. 98                  4. 668
WEIGHTED TEST MILEAGE             10. 99                  4. 673

                    WEIGHTED MASS EMISSIONS

            CO        6. 459 G/MILE       4. 013 G/KM
            HC        1. 329              0. 826
            NOX       1. 730              1. 075
  CORRECTED NOX       1. 738              1. 080
            CO2     796. 063            494. 650
            SO2       0. 0                0. 0
            SO2       0. 0                0. 0     UNWEIGHTED
READY
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```
 SAVED
 READY
EXEC (LUNT4)
 DATE 11/4/77                   VEHICLE NO. 26                 MAKE NOVA
 STAND 2                        ODOMETER 33516.
 FUEL INDOLENE

 WET BULB TEMP    68.0          ABSOLUTE HUMIDITY   96.0 GRNS/LBS DRY AIR
 DRY BULB TEMP    73.0          RELATIVE HUMIDITY   78.0 PCT
 BAROMETRIC PRES  771.          PUMP INLET PRES.     7.30 INCHES OF H2O

                             MEASURED CONCENTRATIONS
  BAG             1      AIR(1)     2       AIR(2)     3       AIR(3)

 CO,PPM       677.50      9.60    83.50      9.60   380.00      7.00
 HC,PPM C6     21.00      1.66     7.20      1.48    13.60      1.76
 NOX,PPM       49.50      0.34    22.00      0.48    39.00      0.45
 CO2,PCT        2.04      0.05     1.43      0.05     1.77      0.05
 SO2,PPM        0.0                0.0               0.0

 PUMP REV     9560.              16370.             9540.
 TEMP            130.  F








 ***
 PUMP CAPACITY    0.3160 CF/REV


                       RESULTS
 BAG          1           2           3

 VMIX       2694.       4613.       2688.
 DF           6.33        9.32        7.38

                MASS EMISSIONS, GRAMS/BAG

 CO          55.60       10.76       31.16
 HC           5.17        2.66        3.18
 NOX          7.18        5.39        5.62
 CO2       2798.14     3304.18     2411.27
 CARBON     791.91      908.60      674.14
 SO2          0.0         0.0         0.0

 FUEL
 LBS/BAG      2.01        2.31        1.71

                                      INDOLENE MILEAGE
 AVERAGE COLD START MILEAGE       10.72 MILES/GAL      4.558 KM/LITRE
```

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***
AVERAGE HOT START MILEAGE         11. 52                 4. 897
OVERALL TEST MILEAGE              11. 26                 4. 787
WEIGHTED TEST MILEAGE             11. 16                 4. 745

                          WEIGHTED MASS EMISSIONS

                    CO        6. 991 G/MILE         4. 344 G/KM
                    HC        0. 893                0. 555
                    NOX       1. 558                0. 968
          CORRECTED NOX       1. 728                1. 074
                    CO2     784. 240              487. 304
                    SO2       0. 0                  0. 0
                    SO2       0. 0                  0. 0     UNWEIGHTED
 READY
QE
```

```
 SAVED
 READY
EXEC (LUNT4)
 DATE 11/9/77                      VEHICLE NO. 26                  MAKE NOVA
 STAND 2                           ODOMETER 35158.
 FUEL INDOLENE

 WET BULB TEMP     68.0            ABSOLUTE HUMIDITY   90.0 GRNS/LBS DRY AIR
 DRY BULB TEMP     76.0            RELATIVE HUMIDITY   67.0 PCT
 BAROMETRIC PRES.  764.            PUMP INLET PRES.     7.25 INCHES OF H2O

                              MEASURED CONCENTRATIONS
  BAG              1       AIR(1)      2       AIR(2)      3       AIR(3)

 CO,PPM        600.00      10.50     75.50      7.00    144.50      3.00
 HC,PPM C6      19.20       1.46      5.30      1.47      9.00      1.32
 NOX,PPM        65.00       0.47     26.50      0.41     50.00      0.40
 CO2,PCT         1.95       0.05      1.34      0.04      1.65      0.04
 SO2,PPM         0.0                  0.0                 0.0

 PUMP REV      9560.                16380.              9570.
 TEMP            130.  F
 ***




 PUMP CAPACITY    0.3160 CF/REV


                    RESULTS
 BAG           1            2            3

 VMIX        2670.        4574.        2672.
 DF            6.64         9.94         8.01

              MASS EMISSIONS, GRAMS/BAG

 CO           48.92         9.92        11.82
 HC            4.70         1.78         2.05
 NOX           9.34         6.47         7.19
 CO2        2646.20      3087.89      2243.29
 CARBON      747.17       848.46       619.03
 SO2           0.0          0.0          0.0

 FUEL
 LBS/BAG      1.90         2.16         1.57

                                     INDOLENE MILEAGE
 AVERAGE COLD START MILEAGE       11.43 MILES/GAL      4.858 KM/LITRE
 ***
```

```
AVERAGE HOT START MILEAGE         12.42                    5.282
OVERALL TEST MILEAGE              12.07                    5.133
WEIGHTED TEST MILEAGE             11.97                    5.091

                       WEIGHTED MASS EMISSIONS

              CO        5.025 G/MILE          3.123 G/KM
              HC        0.663                 0.412
              NOX       1.945                 1.208
    CORRECTED NOX       2.092                 1.300
              CO2     733.923               456.039
              SO3       0.0                   0.0
              SO2       0.0                   0.0       UNWEIGHTED
READY
```

```
EXEC (LUNT4)
DATE 11/10/77                   VEHICLE NO.  26              MAKE  NOVA
STAND    2                      ODOMETER   35180.
FUEL   INDOLENE

WET BULB TEMP      67.0         ABSOILUTE HUMIDITY   90.0 GRNS/LBS DRY AIR
DRY BULB TEMP      73.0         RELAITIVE HUMIDITY   74.0 PCT
BAROMETRIC PRES.  757.          PUMP' INLET PRES.     7.15 INCHES OF H2O

                            MEASURED  CONCENTRATIONS
 BAG               1       AIR(1)       2       AIR(2)       3       AIR(3)

CO,PPM          593.80      1.00      67.50      1.00     168.50      1.00
HC,PPM C6        19.60      1.20       6.00      0.98       9.40      1.02
NOX,PPM          58.50      0.23      25.00      0.20      48.50      0.20
CO2,PCT           2.06      0.05       1.41      0.04       1.80      0.05
SO2,PPM           0.0                  0.0                  0.0

PUMP REV       9560.                16380.               9560.
TEMP               128.  F
PUMP CAPACITY       0.3160 CF/REV


***









                        RESULTS
BAG            1              2              3

VMIX         2654.          4548.          2654.
DF             6.30           9.42           7.36

               MASS EMISSIONS, GRAMS/BAG

CO            48.59           9.47          13.81
HC             4.83           2.28           2.22
NOX            8.38           6.11           6.95
CO2         2780.23        3247.64        2423.75
CARBON       783.73         892.30         669.26
SO2            0.0            0.0            0.0

FUEL
LBS/BAG        1.99           2.27           1.70

                                         INDOLENE MILEAGE
AVERAGE COLD START MILEAGE       10.88 MILES/GAL       4.625 KM/LITRE
AVERAGE HOT START MILEAGE        11.68                 4.964
OVERALL TEST MILEAGE             11.40                 4.847
WEIGHTED TEST MILEAGE            11.32                 4.812
***
```

```
                       WEIGHTED MASS EMISSIONS
           CO          5.098 G/MILE          3.168 G/KM
           HC          0.750                 0.466
           NOX         1.824                 1.133
 CORRECTED NOX         1.962                 1.219
           CO2       776.623               482.571
           SO2         0.0                   0.0
           SO2         0.0                   0.0      UNWEIGHTED
READY
```

```
 SAVED
 READY
EXEC (LUNT4)
 DATE 11/22/77                  VEHICLE NO. 26                 MAKE NOVA
 STAND 2                        ODOMETER 35963.
 FUEL CX-82

 WET BULB TEMP     60.0         ABSOLUTE HUMIDITY   58.0 GRNS/LBS DRY AIR
 DRY BULB TEMP     72.0         RELATIVE HUMIDITY   50.0 PCT
 BAROMETRIC PRES.  773.         PUMP INLET PRES.     7.30 INCHES OF H2O

                           MEASURED CONCENTRATIONS
  BAG            1        AIR(1)      2       AIR(2)     3        AIR(3)

 CO,PPM       930.00      7.00     49.00      3.00    140.00      3.00
 HC,PPM C6     17.60      1.04      3.60      1.00      6.40      1.14
 NOX,PPM       64.00      0.31     29.50      0.35     60.50      0.30
 CO2,PCT        1.93      0.06      1.28      0.05      1.67      0.06
 SO2,PPM        0.0                 0.0                 0.0

 PUMP REV      9590.               16350.              9560.
 TEMP            120.  F
 ***


 PUMP CAPACITY    0.3170 CF/REV


                       RESULTS
 BAG           1             2             3

 VMIX        2765.         4714.         2756.
 DF            6.61         10.43          7.95

              MASS EMISSIONS, GRAMS/BAG

 CO           79.73          6.89         11.88
 HC            4.53          1.25          1.46
 NOX           9.55          7.45          8.99
 CO2        2695.09       3004.56       2310.79
 CARBON      773.58        823.96        636.95
 SO2           0.0           0.0           0.0

 FUEL
 LBS/BAG       1.97          2.10          1.62

                                  INDOLENE MILEAGE
 AVERAGE COLD START MILEAGE      11.41 MILES/GAL     4.852 KM/LITRE
 ***
```

$\frac{2234.49\ g\ C}{.860} = 2598.2\ g\ F$

$\times \frac{1\ lb}{454\ g} \times \frac{1\ gal}{6.0721\ lb} = 0.943\ gal$

```
AVERAGE HOT START MILEAGE         12.48                    5.306
OVERALL TEST MILEAGE              11.97                    5.088
WEIGHTED TEST MILEAGE             12.00                    5.101

                    WEIGHTED MASS EMISSIONS

            CO         6.393 G/MILE         3.972 G/KM
            HC         0.537                0.333
            NOX        2.224                1.382
  CORRECTED NOX        2.060                1.280
            CO2      730.746              454.064
            SO2        0.0                  0.0
            SO2        0.0                  0.0      UNWEIGHTED
READY
```

```
 SAVED
 READY
EXEC (LUNT4)
 DATE 11/23/77                      VEHICLE NO. 26                  MAKE NOVA
 STAND 2                            ODOMETER 35985.
 FUEL CX-82

 WET BULB TEMP     62.0             ABSOLUTE HUMIDITY    67.0 GRNS/LBS DRY AIR
 DRY BULB TEMP     72.0             RELATIVE HUMIDITY    57.0 PCT
 BAROMETRIC PRES.  770.             PUMP INLET PRES.      7.30 INCHES OF H2O

                              MEASURED CONCENTRATIONS
  BAG              1        AIR(1)       2        AIR(2)       3        AIR(3)

 CO,PPM        587.50        7.00      77.50       8.80    577.50       7.90
 HC,PPM C6      14.40        1.80       4.00       2.40      7.60       1.90
 NOX,PPM        57.50        0.75      23.30       0.57     43.00       0.29
 CO2,PCT         1.98        0.05       1.40       0.05      1.80       0.05
 SO2,PPM         0.0                    0.0                  0.0

 PUMP REV      9560.                 16370.                9590.
 TEMP              125. F
 PUMP CAPACITY      0.3160 CF/REV
 ***




                          RESULTS
 BAG            1              2              3

 VMIX         2714.          4647           2722.
 DF              6.55           9.50           7.21

             MASS EMISSIONS, GRAMS/BAG

 CO             49.07          10.15          48.48
 HC              3.42           0.84           1.59
 NOX             8.36           5.74           6.38
 CO2          2725.67        2256.51        2485.81
 CARBON        767.92         893.76         700.92
 SO2             0.0            0.0            0.0

 FUEL
 LBS/BAG         1.95           2.27           1.78

                                         INDOLENE MILEAGE
 AVERAGE COLD START MILEAGE          10.97 MILES/GAL       4.665 KM/LITRE
 AVERAGE HOT START MILEAGE           11.44                 4.862
 ***
```

[illegible] = .996 gal

```
OVERALL TEST MILEAGE                 11.32                 4.813
WEIGHTED TEST MILEAGE                11.23                 4.775


                    WEIGHTED MASS EMISSIONS

            CO        7.851 G/MILE        4.878 G/KM
            HC        0.430               0.267
            NOX       1.723               1.071
  CORRECTED NOX       1.660               1.032
            CO2     779.393             484.292
            SO2       0.0                 0.0
            SO2       0.0                 0.0    UNWEIGHTED
READY
```

? Rerun

```
SAVED
READY
EXEC (LUNT4)
 DATE 11/29/77                    VEHICLE NO. 26                 MAKE NOVA
 STAND 2                          ODOMETER 36244.
 FUEL C-82

 WET BULB TEMP      57.5          ABSOLUTE HUMIDITY   54.0 GRNS/LBS DRY AIR
 DRY BULB TEMP      68.0          RELATIVE HUMIDITY   53.0 PCT
 BAROMETRIC PRES.  778.           PUMP INLET PRES.     7.30 INCHES OF H2O

                        MEASURED CONCENTRATIONS
  BAG             1        AIR(1)      2       AIR(2)       3       AIR(3)

 CO, PPM        593.80      5.00     70.00      4.00     170.50      3.00
 HC, PPM C6      16.60      2.00      4.60      2.20       8.70      2.00
 NOX, PPM        67.50      0.53     26.00      0.62      54.50      0.40
 CO2, PCT         1.82      0.05      1.19      0.05       1.50      0.05
 SO2, PPM         0.0                 0.0                  0.0

 PUMP REV       9590.               16390.               9600.
 TEMP             125.  F
 ***



 PUMP CAPACITY    0.3160 CF/REV

                   RESULTS
 BAG          1             2             3

 VMIX       2751          4701.         2754.
 DF           7.11         11.16          8.81

           MASS EMISSIONS, GRAMS/BAG

 CO          50.66          9.86         14.53
 HC           4.01          1.20          1.87
 NOX          9.99          6.48          8.08
 CO2       2528.29       2783.44       2078.42
 CARBON     715.15        764.84        575.04
 SO2          0.0           0.0           0.0

 FUEL
 LBS/BAG       1.82          1.95          1.46

                                     INDOLENE MILEAGE
 AVERAGE COLD START MILEAGE        12.32 MILES/GAL      5.237 KM/LITRE
 ***
```

.4536 kg/lb

– 2055.03 gs Carbon

4.53 lb. Carbon

.859 ?

5.274 lb fuel.

= .868

13.24

```
AVERAGE HOT START MILEAGE        13. 61                    5. 785
OVERALL TEST MILEAGE             13. 01                    5. 532
WEIGHTED TEST MILEAGE            13. 02                    5. 536

                     WEIGHTED MASS EMISSIONS

            CO          5. 324 G/MILE         3. 308 G/KM
            HC          0. 532                0. 330
            NOX         2. 050                1. 274
  CORRECTED NOX         1. 866                1. 159
            CO2       674. 041              418. 829
            SO2         0. 0                  0. 0
            SO2         0. 0                  0. 0      UNWEIGHTED
READY
```

```
 SAVED
 READY
EXEC (LUNT4)
 DATE 11/30/77                    VEHICLE NO. 26                   MAKE NOVA
 STAND 2                          ODOMETER 36285.
 FUEL C-82

 WET BULB TEMP     62.0           ABSOLUTE HUMIDITY   67.0 GRNS/LBS DRY AIR
 DRY BULB TEMP     72.0           RELATIVE HUMIDITY   57.0 PCT
 BAROMETRIC PRES.  772.           PUMP INLET PRES.     7.25 INCHES OF H2O

                             MEASURED CONCENTRATIONS
  BAG                1        AIR(1)      2       AIR(2)     3       AIR(3)

 CO,PPM         479.00      5.00     81.50     5.00    215.00     5.00
 HC,PPM C6       15.00      1.66      4.90     1.64      9.00     1.64
 NOX,PPM         63.50      0.42     23.50     0.42     50.00     0.39
 CO2,PCT          2.04      0.05      1.36     0.06      1.67     0.06
 SO2,PPM         0.0                  0.0                 0.0

 PUMP REV      9580.              16360.               9570.
 TEMP              125.  F
 PUMP CAPACITY    0.3170 CF/REV
 ***




                         RESULTS
 BAG            1               2              3

 VMIX         2735.           4671.          2733.
 DF             6.40            9.00           7.91

             MASS EMISSIONS, GRAMS/BAG

 CO            40.33           11.31          18.00
 HC             3.64            1.57           2.03
 NOX            9.35            5.05           7.35
 CO2         2827.28         3145.37        2291.46
 CARBON       792.00          864.56         634.80
 SO2           0.0             0.0            0.0

 FUEL
 LBS/BAG         2.01            2.20           1.61

                                         INDOLENE MILEAGE
 AVERAGE COLD START MILEAGE          11.01 MILES/GAL       4.679 KM/LITRE
 AVERAGE HOT START MILEAGE           12.16                 5.170
 ***
```

— 2291.36 g
5.05 lb/E
.859

= 5.8816 fuel
= .96865 ga
11.87 mpg.

```
OVERALL TEST MILEAGE              11.67                4.961
WEIGHTED TEST MILEAGE             11.64                4.947

                    WEIGHTED MASS EMISSIONS

            CO        5.189 G/MILE        3.225 G/KM
            HC        0.572               0.355
            NOX       1.875               1.165
  CORRECTED NOX       1.807               1.123
            CO2     755.631             469.527
            SO2       0.0                 0.0
            SO2       0.0                 0.0     UNWEIGHTED
READY
```

```
 SAVED
 READY
EXEC (LUNT4)
 DATE 12/9/77                      VEHICLE NO. 26                   MAKE NOVA
 STAND 2                           ODOMETER 40667.
 FUEL TK90

 WET BULB TEMP     60.0            ABSOLUTE HUMIDITY   58.0 GRNS/LBS DRY AIR
 DRY BULB TEMP     74.0            RELATIVE HUMIDITY   50.0 PCT
 BAROMETRIC PRES.  754.            PUMP INLET PRES.     7.10 INCHES OF H2O

                             MEASURED CONCENTRATIONS
  BAG              1        AIR(1)      2        AIR(2)      3       AIR(3)

 CO,PPM       1600.00       20.00    115.50       4.00    366.30      1.00
 HC,PPM C6      23.00        1.18      5.50       1.24     11.20      0.80
 NOX,PPM        63.00        0.57     26.00       0.35     54.00      0.30
 CO2,PCT         1.95        0.05      1.25       0.05      1.66      0.04
 SO2,PPM         0.0                   0.0                  0.0

 PUMP REV      9570.                16390.               9590.
 TEMP             124.  F
 ***




  PUMP CAPACITY    0.3170 CF/REV


                          RESULTS
  BAG            1              2              3

  VMIX         2673.          4578.          2679.
  DF              6.34         10.60            7.87

                 MASS EMISSIONS, GRAMS/BAG

  CO           131.99          16.20          30.72
  HC             5.76           1.96           2.76
  NOX            9.05           6.37           7.60
  CO2         2644.50        2870.59        2257.20
  CARBON       702.25         792.01         631.53
  SO2            0.0            0.0            0.0

  FUEL
  LBS/BAG        1.39           2.01           1.61

                                            INDOLENE MILEAGE
  AVERAGE COLD START MILEAGE          11.57 MILES/GAL       4.921 KM/LITRE
  ***
```

```
AVERAGE HOT START MILEAGE       12.81                   5.445
OVERALL TEST MILEAGE            12.12                   5.152
WEIGHTED TEST MILEAGE           12.23                   5.206

                     WEIGHTED MASS EMISSIONS

            CO       12.061 G/MILE           7.495 G/KM
            HC        0.802                  0.498
            NOX       1.961                  1.218
  CORRECTED NOX       1.816                  1.128
            CO2     705.911                438.633
            SO2       0.0                    0.0
            SO2       0.0                    0.0      UNWEIGHTED
READY
```

```
 SAVED
 READY
EXEC (LUNT4)
 DATE 12/13/77                VEHICLE NO. 26                 MAKE NOVA
 STAND 2                      ODOMETER 40829
 FUEL INDOLENE

 WET BULB TEMP     58.0       ABSOLUTE HUMIDITY   52.0 GRNS/LBS DRY AIR
 DRY BULB TEMP     70.5       RELATIVE HUMIDITY   48.0 PCT
 BAROMETRIC PRES.  771.       PUMP INLET PRES.     7.20 INCHES OF H2O

                          MEASURED CONCENTRATIONS
  BAG             1      AIR(1)     2      AIR(2)     3      AIR(3)

 CO,PPM       577.50    10.50   126.00    14.00   271.30     3.00
 HC,PPM C6     18.40     1.50     5.40     1.76    10.80     1.42
 NOX,PPM       54.50     0.47    22.00     0.52    48.00     0.29
 CO2,PCT        1.98     0.05     1.31     0.06     1.65     0.05
 SO2,PPM        0.0               0.0               0.0

 PUMP REV     9560.             16360.            9580.
 TEMP           124.  F
 ***





 PUMP CAPACITY    0.3170 CF/REV


                   RESULTS
 BAG          1           2           3

 VMIX      2731.       4674.       2737.
 DF          6.54       10.09        7.95

           MASS EMISSIONS, GRAMS/BAG

 CO         48.42       16.71       23.09
 HC          4.58        1.75        2.56
 NOX         8.00        5.45        7.08
 CO2      2743.28     3055.18     2285.05
 CARBON    773.35      842.41      635.69
 SO2         0.0         0.0         0.0

 FUEL
 LBS/BAG      1.97        2.14        1.62

                                     INDOLENE MILEAGE
 AVERAGE COLD START MILEAGE       11.28 MILES/GAL.      4.797 KM/LITRE
 ***
 AVERAGE HOT START MILEAGE        12.33                    5.244
 OVERALL-TEST MILEAGE             11.88                    5.049
 WEIGHTED TEST MILEAGE            11.86                    5.042

                         WEIGHTED MASS EMISSIONS

              CO        6.759 G/MILE          4.200 G/KM
              HC        0.690                 0.429
              NOX       1.723                 1.071
    CORRECTED NOX       1.555                 0.966
              CO2     738.302               458.760
              SO2       0.0                   0.0
              SO2       0.0                   0.0      UNWEIGHTED
 READY
QE LUNT
```

```
 SAVED
 READY
EXEC (LUNT4)
 DATE 12/14/77                     VEHICLE NO. 26                      MAKE NOVA
 STAND 2                           ODOMETER 40872.
 FUEL INDOLENE

 WET BULB TEMP     64. 0           ABSOLUTE HUMIDITY   73. 0 GRNS/LBS DRY AIR
 DRY BULB TEMP     74. 0           RELATIVE HUMIDITY   58. 0 PCT
 BAROMETRIC PRES.  766.            PUMP INLET PRES.     7. 10 INCHES OF H2O

                              MEASURED CONCENTRATIONS
  BAG               1        AIR(1)     2       AIR(2)      3       AIR(3)

 CO, PPM       463. 80     20. 00    126. 00     7. 00    292. 50     8. 80
 HC, PPM C6     15. 00      1. 44      5. 40     1. 28      9. 40     1. 34
 NOX, PPM       50. 00      0. 53     22. 00     0. 50     46. 50     0. 52
 CO2, PCT        1. 91      0. 05      1. 35     0. 05      1. 63     0. 05
 SO2, PPM        0. 0                  0. 0                 0. 0

 PUMP REV      3610.                16400.               9570.
 TEMP             125.  F
 ***




 PUMP CAPACITY    0. 3170 CF/REV


                       RESULTS
 BAG            1              2              3

 VMIX        2723.           4647           2712.
 DF            6. 83           9. 84          8. 08

                 MASS EMISSIONS, GRAMS/BAG

 CO           37. 83         17. 50         24. 17
 HC            3. 67          1. 94          2. 19
 NOX           7. 31          5. 42          6. 76
 CO2        2629. 02       3126. 51       2218. 43
 CARBON      726. 04        862. 38        617. 65
 SO2           0. 0           0. 0           0. 0

 FUEL
 LBS/BAG       1. 87          2. 1           1. 57

                                      INDOLENE MILEAGE
 AVERAGE COLD START MILEAGE      11. 40 MILES/GAL      4. 847 KM/LITRE
 ***
```

```
AVERAGE HOT START MILEAGE        12.32                 5.237
OVERALL TEST MILEAGE             12.06                 5.128
WEIGHTED TEST MILEAGE            11.91                 5.062

                    WEIGHTED MASS EMISSIONS

             CO        6.339 G/MILE        3.939 G/KM
             HC        0.635               0.394
             NOX       1.656               1.029
   CORRECTED NOX       1.641               1.020
             CO2     736.199             457.453
             SO2       0.0                 0.0
             SO2       0.0                 0.0     UNWEIGHTED
READY
```

```
 SAVED
 READY
EXEC (LUNT4)
 DATE 12/15/77                    VEHICLE NO. 26                    MAKE NOVA
 STAND 2                          ODOMETER 40910
 FUEL CX-86

 WET BULB TEMP     67.0           ABSOLUTE HUMIDITY   81.0 GRNS/LBS DRY AIR
 DRY BULB TEMP     78.0           RELATIVE HUMIDITY   56.0 PCT
 BAROMETRIC PRES.  758.           PUMP INLET PRES      7.10 INCHES OF H2O

                               MEASURED CONCENTRATIONS
  BAG              1       AIR(1)     2       AIR(2)      3       AIR(3)

 CO,PPM        348.80       3.00   142.50       3.00   260.00      3.00
 HC,PPM C6      17.40       0.84     5.80       0.90    10.00      0.96
 NOX,PPM        71.00       0.30    31.00       0.26    67.00      0.40
 CO2,PCT         1.88       0.04     1.36       0.04     1.63      0.04
 SO2,PPM         0.0                 0.0                 0.0

 PUMP REV     9570.             16400.              9560.
 TEMP            128.  F
 PUMP CAPACITY    0.3160 CF/REV
 ***




                       RESULTS
 BAG            1           2           3

 VMIX        2661.       4560.       2658
 DF             6.98        9.76        8.09

              MASS EMISSIONS, GRAMS/BAG

 CO            28.72       20.08       21.44
 HC             4.35        2.23        2.39
 NOX           10.20        7.60        9.60
 CO2         2533.69     3121.26     2191.39
 CARBON       709.15      862.31      609.27
 SO2            0.0         0.0         0.0

 FUEL
 LBS/BAG        1.80        2.19        1.55

                                     INDOLENE MILEAGE
 AVERAGE COLD START MILEAGE       11.60 MILES/GAL      4.933 KM/LITRE
 AVERAGE HOT START MILEAGE        12.39                5.267
 ***
```

```
OVERALL TEST MILEAGE                12.26                    5.213
WEIGHTED TEST MILEAGE               12.04                    5.118


                         WEIGHTED MASS EMISSIONS

            CO         5.953 G/MILE            3.699 G/KM
            HC         0.728                   0.452
            NOX        2.327                   1.446
  CORRECTED NOX        2.394                   1.488
            CO2      728.322                 452.558
            SO2        0.0                     0.0
            SO2        0.0                     0.0     UNWEIGHTED
READY
```

```
EXEC (LUNT4)
DATE 12/16/77                     VEHICLE NO. 26                  MAKE NOVA
STAND 2.                          ODOMETER 40956.95
FUEL CX86

WET BULB TEMP     59.0            ABSOLUTE HUMIDITY   55.0 GRNS/LBS DRY AIR
DRY BULB TEMP     71.0            RELATIVE HUMIDITY   48.5 PCT
BAROMETRIC PRES.  767.            PUMP INLET PRES.     7.00 INCHES OF H2O

                              MEASURED CONCENTRATIONS
 BAG               1       AIR(1)     2       AIR(2)      3       AIR(3)

CO,PPM       1325.00        8.90    128.30     7.00    275.00      4.30
HC,PPM C6      23.00        1.28      5.80     1.47     22.00      1.34
NOX,PPM        89.50        0.55     35.50     0.43     76.00      0.55
CO2,PCT         1.92        0.04      1.31     0.04      1.65      0.04
SO2,PPM         0.0                   0.0                0.0

PUMP REV     9560.                16360.             9550.
TEMP           130.  F
PUMP CAPACITY    0.3165 CF/REV


***









                    RESULTS
BAG           1           2           3

VMIX        2686.       4597        2683.
DF            6.51       10.11        7.93

              MASS EMISSIONS, GRAMS/BAG

CO          110.51       17.71       22.85
HC            5.77        2.02        5.48
NOX          12.95        8.74       10.98
CO2        2624.58     3032.08     2244.57
CARBON      768.61      836.77      627.07
SO2           0.0         0.0         0.0
```

– 2232.45 g C. – .902 gal

```
FUEL
LBS/BAG       1.95        2.13        1.59

                                  INDOLENE MILEAGE
AVERAGE COLD START MILEAGE       11.36 MILES/GAL      4.828 KM/LITRE
AVERAGE HOT START MILEAGE        12.45                5.295
OVERALL TEST MILEAGE             11.98                5.092
WEIGHTED TEST MILEAGE            11.96                5.084
***
```

```
                          WEIGHTED MASS EMISSIONS

                   CO        10.434 G/MILE            6.483 G/KM
                   HC         1.016                   0.631
                   NOX        2.742                   1.704
         CORRECTED NOX        2.507                   1.558
                   CO2      725.340                 450.705
                   SO2        0.0                     0.0
                   SO2        0.0                     0.0      UNWEIGHTED
      READY
```

APPENDIX C

OCTANE REQUIREMENT INFORMATION

C-1	Technique for Determination of Octane Number Requirements of Passenger Cars (CRC E-15-78)
C-2	RON and RON for Full-Boiling Range Octane Rating Fuels
C-3 through C-11	Octane Rating Data for Vehicle with Knock-Sensor Spark Retard System

APPENDIX C-1

TECHNIQUE FOR DETERMINATION OF OCTANE NUMBER REQUIREMENTS OF PASSENGER CARS

(CRC Designation E-15-78)

Revised
June 1977

TECHNIQUE FOR DETERMINATION OF OCTANE NUMBER REQUIREMENTS OF PASSENGER CARS

(CRC Designation E-15-78)

A. GENERAL

The technique provides for the determination of octane number requirements of a vehicle in terms of borderline spark knock or surface ignition knock, regardless of throttle position, on one or more series of full-boiling range reference fuels as well as on primary reference fuels. It also provides octane requirements throughout the speed range on primary reference fuels.

Spark knock, surface ignition and after-run characteristics of tank fuel will also be described.

B. DEFINITION OF TERMS

1. The following definitions of knock were approved by the CFR and CLR Committees on June 8, 1954, and will be used in this technique.

   Knock is the noise associated with autoignition* of a portion of the fuel-air mixture ahead of the advancing flame front. The flame front is presupposed to be moving at normal velocity. With this definition the source of the normal flame front is immaterial--it may be the result of surface ignition or spark ignition.

   a. Spark Knock: A knock which is recurrent and repeatable in terms of audibility. It is controllable by the spark advance; advancing the spark increases the knock intensity and retarding the spark reduces the intensity. This definition does not include surface ignition induced knock.

   b. Surface Ignition Knock: Knock which has been preceded by a surface ignition. It is not controllable by spark advance.** It may or may not be recurrent and repeatable.

---

* Autoignition: The spontaneous ignition and the resulting very rapid reaction of a portion or all of the fuel-air mixture. The flame speed is many, many times greater than that which follows normal spark ignition. There is no time reference for autoignition.

** For the purpose of this program, it is not intended that surface ignition knock be identified by manipulation of the spark advance.

2. The following definitions of knock intensity were specifically adopted for use in this technique:

   a. No Knock: This means no spark knock or surface ignition knock.

   b. Borderline Knock: This means spark knock of lowest audible intensity, recurrent surface ignition knock of borderline intensity, or infrequent (three or less) surface ignition knocks regardless of intensity.

   c. Above Borderline Knock: This means greater than borderline spark knock, recurrent surface ignition knock greater than borderline intensity, or frequent (four or more) surface ignition knocks regardless of intensity.

   d. After-Run: The engine continues to operate after the ignition is turned off.

3. Definition of Accelerations

   Accelerations are made at full-throttle and part-throttle conditions which are defined below:

   a. Full-Throttle Acceleration: Full throttle consists of accelerations carried out under maximum or wide-open throttle as specified in the following procedure:

      1) Maximum Throttle: The throttle is depressed and held at detent throughout the acceleration at a position of minimum manifold vacuum for the desired gear (highest gear or passing gear operation for automatic transmissions). The minimum manifold vacuum obtainable on a given model is determined by the transmission characteristics.

      2) Wide-Open Throttle: The throttle is depressed through the downshift point on automatic transmissions and held at the limit of pedal travel throughout the acceleration.

   b. Part-Throttle Acceleration: The throttle is depressed and regulated throughout the acceleration to maintain a desired constant manifold vacuum. This constant manifold vacuum will exceed that obtained at "maximum throttle" and will be within the specified vacuum range of investigation for this program.

C. VEHICLE PREPARATION

The following vehicle preparation steps should be completed before any octane tests are run. Detailed procedures for each adjustment can be found in the manufacturers' shop manuals.

1. Record vehicle identification number and emission control type, Federal, Altitude or California. Fill in heading on data sheet DFMF-11-1178.

2. Inspect all vacuum lines and air pump hoses for appropriate connections. Also check to see if PCV valve, distributor vacuum delay valve, EGR valve and heated inlet air mechanism are functioning. Engine must be warmed up for these checks. If manufacturers' procedures are not provided, check distributor vacuum delay according to Figure 1.

3. Record engine idle speed and observe anti-dieseling solenoid operation. Adjust to manufacturers' recommended specifications as specified on the under-hood decal.

4. Observe and record basic spark timing at recommended engine speed. Adjust to manufacturers' recommended setting as specified on the under-hood decal.

5. Crankcase oil, radiator coolant, automatic transmission fluid, and battery fluid levels shall be maintained as recommended by the manufacturer.

6. A calibrated tachometer graduated in 100 rpm (or smaller) increments and capable of indicating engine speed from 0-5000 rpm shall be installed on each vehicle.

7. One calibrated vacuum gage, graduated in one-half inch of mercury (or smaller) increments and capable of indicating vacuum from 0-24 inches of mercury shall be connected to the intake manifold.

8. An auxiliary fuel system shall be provided to supply test fuels to the engine. Caution shall be taken to avoid placing auxiliary fuel lines in locations which promote vapor lock. If cars with carbureted engines have tank return fuel lines, this return line should be blocked off. Evaporative control systems should be isolated by disconnecting line from fuel tank and the carburetor float bowl if the car is so equipped. Instructions for fuel handling with fuel injection systems is shown in the Appendix.

9. Before starting the octane number requirements tests, a sample of the tank gasoline shall be withdrawn for determination of Research and Motor method octane number ratings.

D. TEST PROCEDURE

1. Engine Warm-Up

a. To stabilize engine temperatures, a minimum of ten miles of warm-up is required. The test vehicle should be operated at 55 mph in top gear with a minimum of full-throttle operation.

b. During the warm-up period, the general mechanical condition of the vehicle should be checked to insure satisfactory and safe operation during test work.

2. Fuel Change-Over

Caution: Because of the installation of catalytic devices on these cars, permanent damage may result if the engine runs over lean or stalls. Therefore, change-over from one fuel to another must be accomplished without running the carburetor or fuel injection system dry. Fuel handling procedures for cars equipped with fuel injection systems are explained in Attachment 1.

To eliminate contamination of the new fuel with residual amounts of the previous fuel, the car will be operated under the following conditions after charging with the new fuel: operate car for 2 miles at a maximum speed of 55 mph during which time four part-throttle accelerations at approximately 4" Hg manifold vacuum are made.

After fuel change-over, make one preliminary acceleration before beginning Vehicle Rating Procedure.

3. Details of Observations

a. Operating Conditions

All octane number requirements will be determined under level road acceleration conditions. Cars equipped with free wheeling or overdrive units shall be tested with this unit (free wheeling or overdrive) locked out of operation. Cars with three-speed and four-speed transmissions shall be run in highest gear. Five-speed transmissions shall be run in fourth gear and automatic transmissions shall be run in "Drive". Test accelerations will be made as described below under 3 d.

Tests will be conducted on moderately dry days preferably at ambient temperatures above 60°F. Tests should not be conducted during periods of high humidity such as prevail when rain is threatening or during or immediately after a rain storm. Laboratories with control capabilities should target for 70°F air temperature and 50 grains of water per pound of dry air whenever possible.

Air conditioned cars will be tested with air conditioner set at the temperature setting to assure continuous compressor operation and on low fan position.

b. Order of Fuel Testing

1. Tank
2. FBRSU
3. FBRU
4. Primary

c. Determination of Knock Intensity

Octane requirements will be established by evaluating the occurrence of knock in terms of knock intensity: "N" for none, "B" for borderline, and "A" for above borderline. Establishment of representative knock intensity for a given fuel will be accomplished with the fewest number of accelerations possible. As defined below, the first two duplicating accelerations are sufficient with "N" and "B" knock intensity.

Number of Accelerations			Representative Rating
1	2	3	
N	N	–	N
N	B	N	N
N	B	B	B
B	N	B	B
B	B	–	B
B	A	–	A
A	–	–	A

All subsequent accelerations will normally be discontinued when "A" knock intensity is experienced and testing continued with a higher octane number fuel in that series. An exception will be made if "A" knock is experienced on the highest octane fuel which knocks in the engine. In this case, it may be necessary to run additional accelerations to determine the speed of maximum knock intensity. If "A" knock is experienced at initiation of acceleration, as limited by transmission characteristics, this speed will be considered the speed of maximum knock. Otherwise, the mid-point between knock-in and knock-out will be considered the speed of maximum knock. When establishing knock-in and knock-out, back off on the throttle between points to eliminate "A" knock.

d. Determination of Maximum Octane Requirement

1) Vehicle Operating Procedure (for driver)

a) For establishment of transmission characteristics, obtain downshift engine rpm and manifold vacuum at 20, 30, 40 and 50 mph by movement of the throttle through the detent position. Record both engine rpm and manifold vacuum at the downshift point for each speed. The vehicle brakes may be applied lightly, if necessary, to maintain vehicle speed. The minimum speeds obtained here will be used for starting speeds for the accelerations in (b), (c) and (e) below.

b) For maximum throttle requirements, accelerate at maximum throttle from minimum obtainable speed as determined in (a)* up to 3500 rpm if necessary in order to define requirements. Tests should be run to 70 mph unless required to terminate at 55 mph because of legal speed limits. If 3500 rpm cannot be attained in top gear, accelerations shall be discontinued and resumed in the next highest gear from 500 rpm below the engine speed at which top gear accelerations were discontinued.

c) For wide-open throttle requirements in passing gear for vehicles with automatic transmissions, accelerate from minimum obtainable engine speed up to 3500 rpm if necessary in order to define requirements. Tests should be run to 70 mph unless required to terminate at 55 mph because of legal speed limits. In some cases it may be necessary to use maximum throttle to the detent position up to the point where wide-open throttle can be obtained.

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* Starting speed for accelerations on manual transmission cars should be the lowest speed from which the vehicle will accelerate smoothly and at an acceptable rate, or 750 rpm, whichever is the greater.

d) For those cars with vacuum delay devices, to stablilize vacuum advance before starting each part-throttle acceleration, operate at road load for 40 seconds at the minimum vehicle speed obtainable before downshift from the highest gear for the manifold vacuum under investigation.

e) For part-throttle requirements, accelerate at constant critical manifold vacuum from minimum obtainable speed to 70 mph unless required to terminate at 55 mph because of legal speed limits or until vehicle ceases to accelerate. To obtain critical part-throttle vacuum, operate at road load for 40 seconds at 30 mph and at 50 mph. At each speed move the throttle from 10 inches vacuum or maximum road load vacuum, whichever is lowest, down to 4 inches vacuum in from 3 to 5 seconds for automatic transmissions. Move the throttle from 10 inches vacuum or maximum road load vacuum, whichever is lowest, down to 2 inches vacuum for manual transmissions. Observe the manifold vacuum for maximum knock and use this critical vacuum for all subsequent part-throttle accelerations.

f) Determination of After-Run Characteristics

Determination of the occurrence of after-run will be evaluated on tank fuel. Following the engine warm-up, moderately brake the vehicle to a stop (foot off throttle) and place automatic transmission cars in park position, manual transmission cars in neutral. Immediately turn key to the off position. Note on the data sheet if after-run occurs.

2) Vehicle Rating Procedure (for rater)

Knock rating should be performed while in a normal seated position with floor mats in place.

Step 1 - Using an estimated non-knocking fuel in a given fuel series, investigate for incidence of knock under conditions as described in 3d (1) (b), and 3d (1) (c) above.

Step 2 - If no knock occurs, go to a lower octane number blend in that series and repeat Step 1.

Step 3 - If knock occurs at one or more of the operating conditions in Step 1, then continue investigation at the critical condition(s) with higher octane blends until highest octane fuel giving knock is determined within one octane number or one blend.

Record maximum knock intensity on all fuels and speed of maximum knock intensity on highest octane fuel that knocks.

Step 4 - Using the highest octane blend that knocked in Step 3 (or lowest octane blend in fuel series if no knock), investigate for incidence of part-throttle knock as described in 3d(1)(e).

Step 5 - If no knock occurs with:

FBRU Fuel, investigate for knock with lower octane fuels until maximum part-throttle requirement is defined down to the limit of the lowest octane fuel available.

The above rating procedure is given in arrow diagram form on page 18.

e. Determination of Supplemental Requirement

1) Tank Fuel Observations

Investigate for full-throttle and part-throttle knock as detailed in Item 3d(1). Define maximum knock intensity as per Item 3c. Record maximum knock intensity, speed of maximum knock intensity and manifold vacuum at each operating condition. Determine after-run characteristics as described in Item 3d(1)(f).

2) Octane Number Requirement Over Speed Range

Octane requirements over the speed range will be obtained on primary reference fuels only. These will be established by recording the knock-in and knock-out points during maximum throttle acceleration with each incremental fuel investigated. It may be necessary to test one or two additional lower octane fuels to describe the knocking characteristics over the speed range from minimum obtainable up to 3500 rpm if necessary in order to find the knock-out point. Accelerate at maximum throttle from minimum obtainable speed as determined in 3d(1)(a) up to 3500 rpm if necessary in order to define requirements. Tests should be run to 70 mph unless required to terminate at 55 mph because of legal speed limits. If 3500 rpm cannot be attained in top gear, accelerations shall be discontinued and resumed in the next highest gear from 500 rpm below the engine speed at which top gear accelerations were discontinued.

When "A" knock is experienced, continue the acceleration but back off on the throttle to maintain "B" knock until just prior to the knock-out point.

E. INTERPRETATION OF DATA

The data will be recorded on data sheet (DFMF-11-1178). Maximum octane requirements for all reference fuels shall be determined as follows:

1. If the knock intensity of the highest fuel giving knock is borderline, the requirement shall be reported as the octane number of that fuel.

2. If the knock intensity of the highest fuel giving knock is above borderline, the requirement shall be reported as one-half the difference between the fuel giving knock and the next highest fuel.

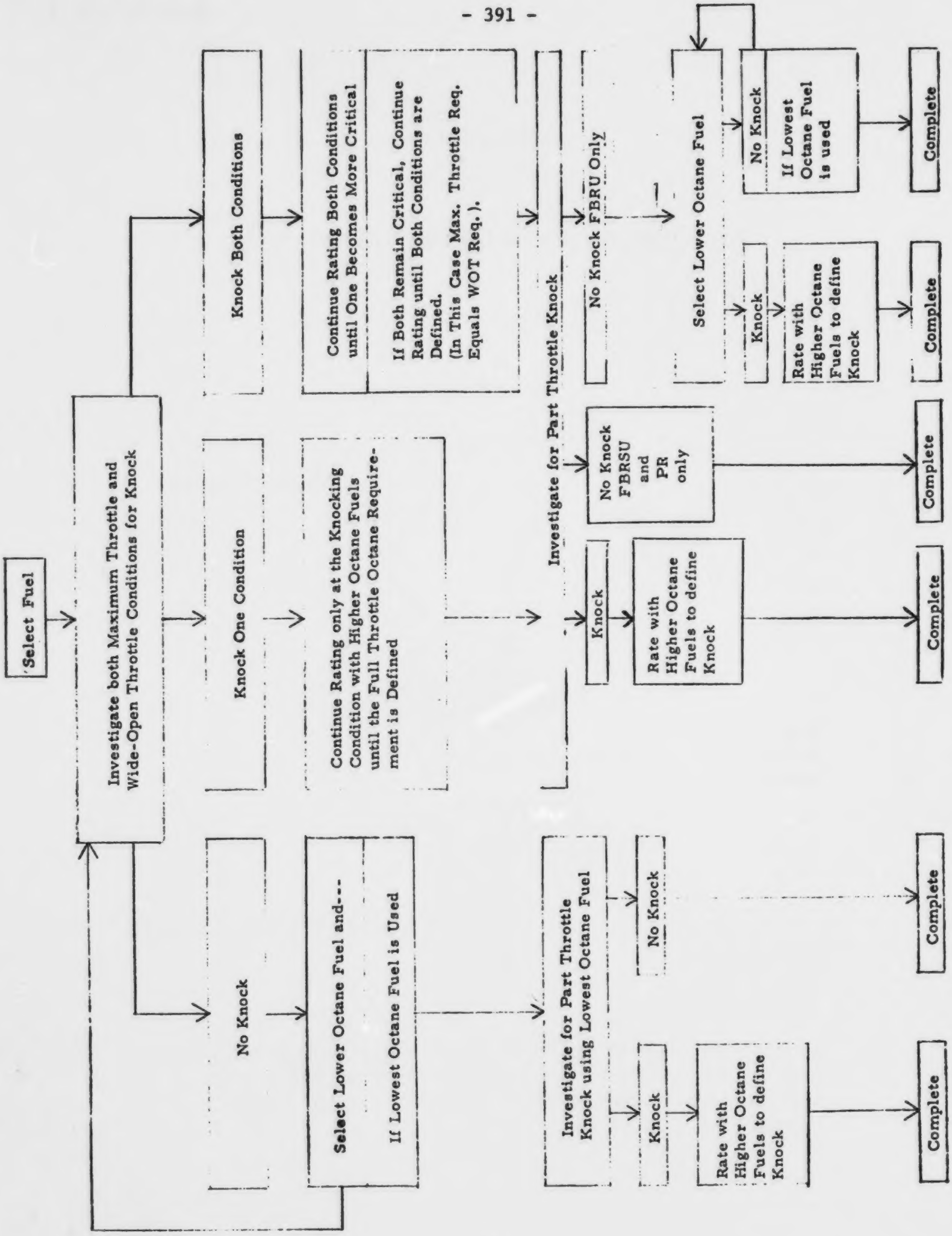
Speed range data shall be reported on data sheet (DFMF-11-1178) as the engine speed of knock-in and knock-out for the octane number of the primary reference fuel tested.

When transferring data to the summary report form, record "no" data as well as "yes" data.

Record data on all fuels tested, even though knock was not encountered. When transferring data to the summary report form (DFMF-15-1178), record results on all fuel series for each throttle condition investigated. Use proper letter designation (see footnotes on summary sheet) to designate requirements outside of the reference fuel limits.

Requirements for the various engine speeds will be determined by fitting a smooth curve through the knock-in and knock-out points on work form (DFMF-12-1178). Primary reference fuel requirements at various engine speeds should be reported to the nearest one-half octane number and recorded on the special speed range summary sheets, (DFMF-25-1178).

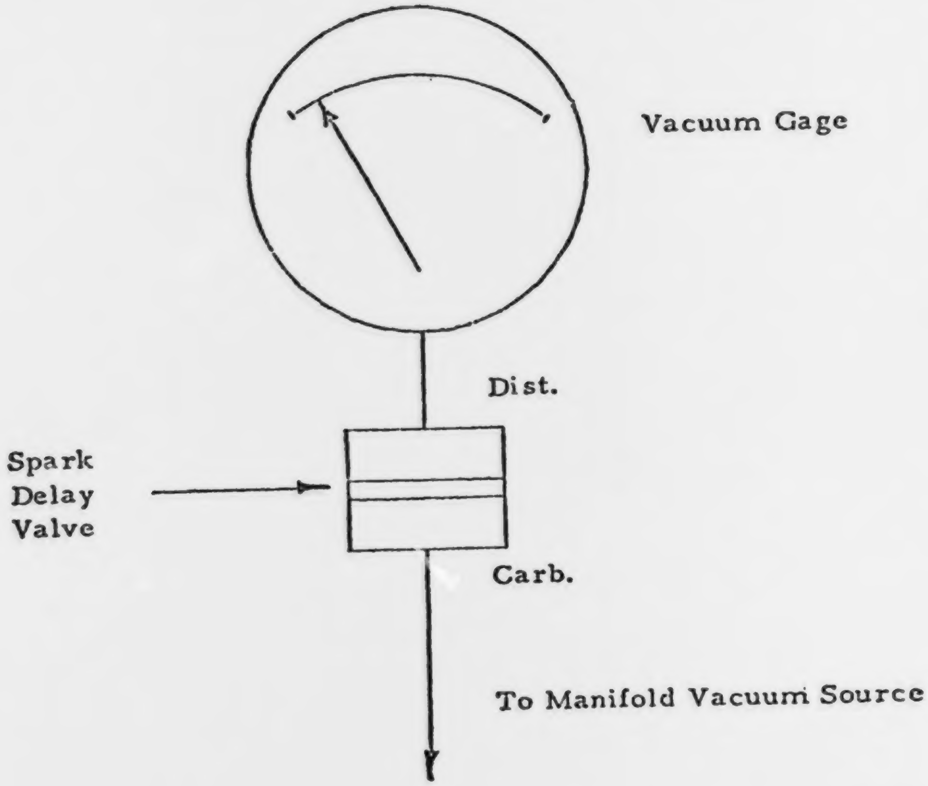
It is important that the serial number (or other identifying number) of each vehicle tested be recorded on all data and summary sheets to provide a means of cross-indexing.


Select Fuel
Investigate both Maximum Throttle and Wide-Open Throttle Conditions for Knock
No Knock
Knock One Condition
Knock Both Conditions
Select Lower Octane Fuel and---
If Lowest Octane Fuel is Used
Continue Rating only at the Knocking Condition with Higher Octane Fuels until the Full Throttle Octane Requirement is Defined
Continue Rating Both Conditions until One Becomes More Critical
If Both Remain Critical, Continue Rating until Both Conditions are Defined. (In This Case Max. Throttle Req. Equals WOT Req.).
Investigate for Part Throttle Knock using Lowest Octane Fuel
Investigate for Part Throttle Knock
Knock
No Knock
Knock
No Knock FBRSU and PR only
No Knock FBRU Only
Rate with Higher Octane Fuels to define Knock
Rate with Higher Octane Fuels to define Knock
Select Lower Octane Fuel
Knock
No Knock
Rate with Higher Octane Fuels to define Knock
If Lowest Octane Fuel is used
Complete
Complete
Complete
Complete
Complete
Complete

Attachment 1

Figure 1

SPARK DELAY VALVE FUNCTIONAL TEST


Vacuum Gage
Dist.
Spark
Delay
Valve
Carb.
To Manifold Vacuum Source

Determine vacuum spark control delay function during tune-up by attaching vacuum gage to distributor side and applying manifold vacuum of at least 10" Hg to carburetor side of device.

APPENDIX
CRC E-15-78

PROCEDURE FOR SETTING UP VEHICLES AND HANDLING REFERENCE FUELS ON VEHICLES EQUIPPED WITH FUEL INJECTION.

1. To run octane requirements on fuel injected vehicles it is necessary to run an external fuel line to the inlet of the vehicle fuel injection pump.

2. The fuel return line from the engine to the fuel tank must be disconnected after the fuel pressure regulator (in engine compartment) and before the fuel tank. An auxiliary line long enough to reach the cans must be added to the fuel return line.

3. Make certain that the fuel tank connections are plugged, this means both the normal fuel pump inlet line and the normal fuel return line connection. On vehicles with an in-tank booster pump, this pump must be shut off so it cannot run during the time the vehicle is operating on the external fuel system. If this pump is not disconnected it will be destroyed.

4. An electric fuel pump (Bendix type acceptable) must be used to draw fuel from the reference fuel can to supply the fuel injection pump on the vehicle. Caution must be exercised to keep the fuel line between the reference fuel cans and the vehicle fuel injection pump full of fuel. If very much air gets into this line, the fuel injection system will become air bound and it is difficult to get the air out of the system.

5. As soon as the fuel injection pump line and fuel return lines have been removed from the vehicle fuel tank, the vehicle can no longer be run on the fuel tank. Any subsequent engine operations will have to be done from an auxiliary fuel tank.

6. It is possible to use three-way valves in the fuel line between the fuel pump and the fuel tank and between the return line and the fuel tank. If they are used, the operator must change the return line valve to the auxiliary fuel system while the engine is shut down to avoid building up excessive pressure in the return line which could do damage to both the fuel pressure regulator and the fuel injection pump.

7. After switching fuel lines to the external fuel cans, the vehicle can no longer be operated on the vehicle fuel tank and all subsequent operations will have to be done from the external system.

8. When changing from one reference fuel to another, the following steps must be followed.

a. Put fuel inlet line in reference fuel tank with the return line going to a slop fuel can. Do not keep fuel inlet line out of a fuel can any longer than is necessary to move it from one can to the next. DO NOT RUN OUT OF FUEL.

b. Observe the fuel stream in the fuel return line. As soon as a steady flow of fuel is observed, move the fuel return line to an empty one quart can. Allow one quart of fuel to flow into this can before inserting the return line into the chosen reference fuel can. This operation should take about 60 seconds.

c. When going to the next reference fuel, it will be necessary to repeat steps a. and b.

The fuel injection pumps on most vehicles pump between 30 and 50 gallons of fuel per hour; therefore, steps a. and b. should be followed very closely or there will be gross reference fuel contamination or you will use a lot more reference fuel than is required to run each test. If steps a. and b. are followed exactly, you will be discarding to slop about two quarts of reference fuel each time you change reference fuels. The two quarts to slop will be at least as much fuel as is consumed to get the reference fuel rating.

OWNER'S QUESTIONNAIRE

CRC OCTANE NUMBER REQUIREMENT SURVEY

OWNER:

Your car is being tested for fuel octane number requirements by the Coordinating Research Council activity. To help analyze the data, we would like the person who has recently been driving the car to answer the following questions:

1. Has any engine knock (or ping) been encountered recently?

☐ Yes ☐ Occasionally

☐ No ☐ Frequently

2. If "yes", was it during any of these conditions?

☐ Low Speed ☐ Hill Climbing ☐ Acceleration

☐ High Speed ☐ Towing Trailer

3. Did you consider the knock objectionable?

☐ Yes ☐ No

4. Did the knock (or ping) occur on the fuel that is now in the tank?

☐ Yes ☐ No

5. Does the engine continue to run after the key is turned off?

☐ Yes ☐ No

Car Make________________________________ License No.__________________

Serial No. ________________________________

APPENDIX C-2

RON AND MON FOR FULL-BOILING RANGE OCTANE RATING FUELS

Nominal RON	High Sensitivity Fuel "CX"		Lower Sensitivity Fuel "C"	
	RON	MON	RON	MON
78	78.0	71.6	77.9	72.6
79	---	---	78.9	73.4
80	80.0	73.4	80.1	74.5
81	---	---	81.0	75.3
82	82.1	74.8	81.9	75.9
83	---	---	83.0	76.8
84	84.0	76.4	84.1	77.7
85	85.3	77.1	85.0	78.5
86	86.2	77.5	86.1	79.2
87	87.3	78.1	87.0	80.0
88	88.3	79.0	88.1	80.5
89	89.2	79.5	89.0	81.3
90	90.0	80.2	90.1	82.2
91	91.1	80.7	91.1	83.0
92	92.0	81.4	92.1	83.7
93	93.0	82.2	93.1	84.3
94	94.2	83.0	94.1	85.0
95	95.2	84.0	95.0	85.8
96	96.1	84.3	96.1	86.8
97	97.2	85.2	97.1	87.5
98	98.1	86.1	98.0	88.4
99	99.1	87.1	99.0	89.4
100	100.0	88.0	100.0	90.1
101	101.0	89.0	100.9	91.2

APPENDIX C-3

Zero Mile (Clean Engine Octane Ratings - MAD

		Box Off		Box On		
Series	RON	Rating	40-70 mph Acceleration Time (Sec)	Rating	°Retard	40-70 mph Acceleration Time (Sec)
CX	86	NK	16.6	NK	2.5°	16.5
	85	T^-	16.2	NK	2.5-4°	17.0
	84	T	16.2	T^-	4°	17.0
	82	VL^-	16.0	T^-	7°	18.0
	80			T	8.5°	18.7
C	85	NK	16.5	NK	2.5°	16.6
	84	T^-	16.4	T^-	2.5°	16.6
	83	T	16.7	T^-	4-5.5°	18.0
	82	T^+	17.4	T^-	4.7°	18.5
	81	VL^-	16.0	T^-	5.5°	18.0
	80			T	8.5°	19.0
	79			T^+	8.5-10°	19.2
P	83	NK	19.8	NK	0-2.5°	19.6
	82	T^-	18.4	T^-	4-5.5°	20.5
	81	T	18.7	T^-	5.5°	20.8
	80	VL^-	17.8	T	5.5-10°	21.8

APPENDIX C-4

Zero Mile (Clean Engine) Octane Ratings - Track (Road)

		Box Off		Box On		
Series	RON	Rating	40-70 mph Acceleration Time (Sec)	Rating	°Retard	40-70 mph Acceleration Time (Sec)
CX	86	NK	13.7	NK	0°	13.8
	85	T^-	13.6	T^-	0°	13.7
	84	T	13.8	T^-	2.5-4°	14.1
	82			T^-	5.5-7°	16.0
	80			T	8.5-10°	18.0
C	84	NK	14.5	NK	0°	14.2
	83	T^-	14.2	NK	2.5-4°	14.9
	82	T	14.5	T^-	5.5°	15.3
	80			T^-	7°	16.3
	79			T^-	8.5°	16.9
	78			T	8.5-10°	17.2
P	83	NK	15.2	NK	2.5°	16.2
	82	T^-	14.9	NK	2.5-4°	15.9
	81	T	15.0	T^-	4-5.5°	16.5
	80			T^-	5.5°	16.5
	79			T	8.5-10°	17.5

APPENDIX C-6

OCTANE REQUIREMENT OF VEHICLE ON MAD DURING MILEAGE ACCUMULATION

6,000 Miles

	Uncontrolled Spark		Controlled Spark		
Fuel RON	Rating	Acc. Time (sec)	Rating	° Retard	Acc. Time (sec)
C 85	NK	17.5	NK	0	17.5
83	T^-	17.7	T^-	0	17.8
82	T	17.7	T^-	5.5	19.8
81	T^+	17.2	T-	7	20.0
80			T	8.5-10	22.3

8,000 Miles

87	NK	15.1	NK	0	15.0
86	T^-	15.5	NK	2.5	16.0
85	T	15.1	T^-	4	16.0
84			T^-	4	16.5
83			T-	5.5-7	17.3
82			T^-	4-7	16.8
81			T	8.5	17.5
80			T^+	8.5-10	18.7

10,000 Miles

88	NK	15.8	NK	0	15.8
87	T^-	15.3	NK	2.5	15.4
86	T-	15.6	T-	2.5-4	16.0
85	T	15.4	T^-	5.5	16.5
84	T^+	15.8	T^-	5.5	16.9
83			T^-	5.5-7	17.3
82			T	7°	18.1
81			T^+	8.5	18.3

APPENDIX C-7

Octane Requirement of Vehicle on MAD @ 12,000 Miles

		Uncontrolled Spark		Controlled Spark		
Series	RON	Rating	Acc. Time(sec.)	Rating	° Retard	Acc. Time
CX	88	NK	16.3	NK	0	16.6
	87	T^-	16.2	NK	2.5	16.8
	86	T^-	16.3	NK	2.5	16.5
	84			T^-	4-5.5	17.5
	82			T	7-8.5	19.0
C	88	NK	15.6	NK	0	15.7
	87	T^-	16.2	T^-	0°	15.8
	86	T	16.2	T^-	4°	17.0
	85	T^+	16.8	T^-	4°	17.2
	84			T	4°	17.0
	83			T	5.5	17.0
	82			T	7-8.5	18.7
	81			T^+	8.5	18.2
P	85	NK	17.0	NK	0	17.2
	84	T^-	17.1	NK	0-2.5	17.3
	83			NK	2.5-4	17.9
	82			T^-	4	18.4
	81			T	4-7	19.2
	80			T	5.5-7	19.7

APPENDIX C-8

Octane Requirement of Vehicle on Road @ 12,000 Miles

		Uncontrolled		Controlled Spark		
Series	RON	Rating	Acc. Time(sec.)	Rating	° Retard	Acc. Time(sec.)
CX	85	NK	14.7	NK	0	15.0
	84	T^-	14.6	T^-	0	14.3
	82	T^+	14.5	T^-	0-4°	14.8
	80			T^+	5.5-7	16.0
	78			VL	5.5-8.5	17.0
C	83	NK	15.3	NK	0	15.5
	81	T^-	15.1	NK	2.5-4	16.0
	80	T	15.3	T^-	2.5-4	16.4
	79	T^+	15.5	T	4-7	16.7
	78			T	5.5-7	17.2
P	82	NK	15.5	NK	0	15.5
	81	T^-	15.1	NK	0-2.5	15.3
	80	T	15.1	NK	2.5-4	15.5
	78			T	5.5	16.5
	77			T^+	7-8.5	18.5

APPENDIX C-9

Vehicle Octane Requirement on MAD After 4,000 Mile AMA Cycle*

		Uncontrolled Spark		Controlled Spark		
Fuel	RON	Rating	Acc. Time(sec)	Rating	° Retard	Acc. Time(sec)
C	88	NK	16.8	NK	0	16.0
	87	T^-	15.8	NK	4°	16.2
	86	T^-	16.0	T^-	4°	16.2
	84	T	16.1	T^-	2.5	16.0
	83	T^+	15.4	T^-	4°	15.7
	81	VL	15.4	T	7°	16.3
P	83	NK	17.7	NK	2.5	17.9
	82	T^-	17.8	T^-	2.5	17.8
	81	T	17.9	T^-	4	18.2
	80			T	5.5	18.1
	78			T^+	10°	19.0

---

* Delay -1 is 128 Engine Revolution, Delay -2 is 32 revolutions. Threshold is 100 mV.

APPENDIX C-10

Vehicle Octane Requirement on Road After 4,000 Mile AMA Cycle*

		Uncontrolled Spark		Controlled Spark		
Fuel	RON	Rating	Acc. Time(sec)	Rating	° Retard	Acc. Time(sec)
C	84	NK	13.7	NK	2.5	14.0
	83	T^-	13.9	NK	2.5-4	14.0
	82	T	13.6	T^-	4-5.5	14.0
	80	VL	13.8	T	8.5	14.7
	79			T	8.5-10	14.7
	78			T^+	8.5-10	14.9
CX	86	NK	13.9	NK	0	13.8
	85	T^-	14.0	NK	4°	14.2
	84	T	14.3	NK	4-5.5	14.1
	80			T	8.5-10	15.2
P	84	NK	14.4	NK	2.5	14.6
	83	T^-	14.2	NK	2.5	14.6
	82	T	14.7	T^-	4-5.5	14.7
	81	T^+	14.6	T	4-7	14.7
	79			T	7-10	15.0
	77			T	10	15.2

---

* Delay -1 is 128 Engine Revolutions, Delay -2 is 32 Engine Revolutions. Threshold is 100 mV.

APPENDIX C-11

Vehicle Octane Requirement on MAD with 12° BTC Basic Timing*

		Uncontrolled Spark		Controlled Spark		
Fuel	RON	Rating	Acc. Time(sec)	Rating	° Retard	Acc. Time(sec)
C	90	NK	15.3	NK	0°	15.1
	89	T⁻	15.4	NK	2.5	15.3
	88	T⁻	15.7	NK	2.5	15.7
	87	T	16.0	T⁻	2.5-4	16.1
	85	VL	15.4	T	5.5	15.9
	83			T	8.5-10	15.9

---

* Delay-1 is 128 engine revolutions; Delay-2 is 32 engine revclutions. Threshold 100 mV.

APPENDIX D

DRIVEABILITY TESTING

D-1 Driveability Fuels

D-2 CRC Driveability Test Procedure

D-3 Driveability Test Results

APPENDIX D-1

DRIVEABILITY FUELS

Fuel	D-1	D-2	D-3	D-4
RVP, psi	7.03	6.87	11.92	11.18
(D+L) at 158°F	9.9	10.0	25.8	32.5
(D+L) at 212°F	47.7	65.7	46.5	64.5
(D+L) at 302°F	87.9	92.9	85.5	93.5
RON	93.5	94.2	98.2	95.0
MON	86.4	85.3	86.9	85.9

All fuels are unleaded

APPENDIX D-2

Proposed
CRC Driveability Test Procedure
(Adapted from AMA Procedure)

I. Cold Start and Driveaway Procedure (Data Sheets 1, 2, and 3)

A. Record all necessary vehicle and test information on data sheet 1.

B. Start engine per Owner's Manual Procedure and record start time.

C. Record engine speed, intake vacuum, and idle quality in Neutral or Park immediately after start, with foot removed from throttle pedal (fast idle cam).

D. If engine stalls, repeat steps B and C.

E. After 5 seconds from start, accelerate engine briefly, and again release throttle; record engine speed, intake vacuum, idle quality, and/or number of stalls. If engine stalls, repeat steps B through E.

F. After 10 seconds from start, apply brakes, shift to normal drive range, and record engine speed, intake vacuum, idle quality, and stalls.

G. After 15 seconds from start, make a light throttle acceleration to 25 mph at a constant throttle opening beginning at a predetermined intake vacuum.* Cruise at 25 mph for 0.1 mile (to check for choke loading), open throttle to detent* and accelerate from 25 to 35 mph at constant throttle in top gear. Decelerate to a stop and accelerate WOT to 35 mph. Decelerate to 10 mph and accelerate 10 to 25 mph constant throttle, beginning at a predetermined intake vacuum.

H. Observe and record any malfunctions such as the following:

1. Hesitations
2. Stumbles
3. Surge
4. Stalls
5. Backfires

I. At 0.5 miles from start, brake moderately to a stop. Idle for 30 seconds in drive range and record engine speed, intake vacuum, and idle quality.

J. Repeat steps G, H, and I through 1.5 miles from start (3 cycles).

---

* All light throttle accelerations are begun by opening the throttle to an initial vacuum which just precedes power enrichment, as indicated by carburetor flow curves. All detent accelerations are begun by opening the throttle to the downshift position as indicated by transmission shift characteristic curves.

K. Make a light throttle acceleration to 45 mph at constant vacuum beginning at a predetermined intake vacuum (crowd condition to check lean operation with choke off). Decelerate 45 to 25 mph, open throttle to detent and accelerate from 25 to 35 mph at constant throttle in top gear. Decelerate to a stop and accelerate WOT to 35 mph. Decelerate to 10 mph and accelerate 10 to 25 mph constant throttle, beginning at a predetermined intake vacuum. Repeat steps H and I above.

L. Repeat step K through 6.4 miles from start (7 cycles).

II. Warm Vehicle Driveability Procedure (Data Sheet 4)

A. Warm up vehicle for about 10 miles at 70 mph.

B. Evaluate curb idle in Neutral and Drive range. Record engine speed, intake vacuum, and idle quality.

C. With transmission in drive range, apply brakes securely and open throttle at a uniform rate to WOT (about 20 sec), allowing transmission torque converter to absorb all of the engine's power. Record any hesitation. stumble, surge, or stall.

D. Cruise at road load from 20 through 70 mph, and record stretchiness and surge.

E. Accelerate WOT from 0 to 30 mph at sudden, moderate, and slow throttle opening rates. Record hesitation, stumble, and surge.

F. Accelerate PT from 0 to 30 mph at constant throttle positions of 1/4, 1/2, and 3/4 throttle, beginning each acceleration at a predetermined intake vacuum. Record hesitation, stumble, and surge.

G. Part throttle crowds are evaluated in high gear at constant vacuum from the minimum speed attainable in high gear to 70 mph (or the maximum speed at each vacuum if less than 70 mph). Several runs are made at different vacuums to determine the worst surge condition. Also record hesitations and stumbles.

H. Evaluate "tip-in" characteristics by making several PT accelerations in high gear from 20 and 30 mph. Do not accelerate at a load which will cause the automatic transmission to downshift. Record hesitations and stumbles.

I. Accelerate WOT from 0 to 70 mph and record acceleration time. Drive 5 miles at 70 mph and brake moderately to a stop. Idle for 30 seconds, shut off engine, and soak for 15 minutes.

J. After hot soak, restart engine according to manufacturer's hot-start procedure (record start time and number of attempts), return to idle, maintain idle for 60 seconds in Neutral (record engine speed, intake vacuum, and idle quality). If engine stalls during the 60 sec. idle, repeat this hot-start and run procedure.

Definitions of Driveability Terms

1. Road Load -- A fixed throttle position which maintains a constant vehicle speed on a level road.

2. Wide Open Throttle (WOT) Acceleration -- An acceleration made entirely at wide open throttle (from any speed).

3. Part Throttle (PT) Acceleration -- An acceleration made at any throttle position less than WOT.

4. Tip-In -- A maneuver to evaluate vehicle response (up to two seconds in duration) to the initial opening of the throttle.

5. Crowd -- An acceleration made at a constant intake vacuum (continually increasing throttle opening).

6. Idle Quality -- An evaluation of vehicle smoothness with the engine idling, as judged from the driver's seat.

7. Backfire -- An explosion in the induction or exhaust system.

8. Hesitation -- A temporary lack of initial response in acceleration rate.

9. Stumble -- A short, sharp reduction in acceleration rate.

10. Stretchiness -- A lack of anticipated response to throttle movement. This may occur on slight throttle movement from road load or during light to moderate accelerations.

11. Surge -- A continued condition of short, sharp fluctuations in power. These may be cyclic or random and can occur at any speed and/or load. Surge is usually caused by over-lean carburetor mixtures.

APPENDIX D-3

Date 10/12/75
Test Number 4
Fuel CR # 29553-D-1

Proposed CRC
Driveability Test
Sheet 1 of 4

Test Vehicle

Make CHEVROLET
Model NOVA #26
Year 1975
Transmission TURBO HYDRAMATIC
A/C NO PB NO PS YES
License No. 735 CPV N.J

Engine Type V-8
Displacement 350 CID
Nominal C.R. 8.5
Carb. Make ROCHESTER No. Bbls. 4
Emission Control System CAL
Odometer: Start 13857 Finish 13880

Weather

C.T.R. ~~Ambient~~ Temp.: Start 70 °F
Finish 69 °F

Observed Barom.: Start 30.03 in. Hg
Finish 30.03 in. Hg

Relative Humidity: Start ____ % 68-56
Finish ____ % 69-58

CLAYTON
~~Road Conditions: Wet~~ ____
Dry ____

Time: Start 1:30
Finish 2:10

Soak Time (hrs.) 2½ HRS
Soak Temp. (°F) 70

Test Crew

Driver WESLEY HOWARTH
Recorder SAMUEL IRWIN

Observers GEORGE BARNES

Remarks

License 735 CPV N.5

S#2 1975 NOVA #26

Cold Start-Driveaway

Start Miles	T # 4 Mode		Idle: Engine Speed rpm	Idle: Intake Vacuum in. Hg	Idle: Satis.	Idle: Rough*	Idle: Stall	Accel. or Cruise: Satis.	Accel. or Cruise: Hesit.*	Accel. or Cruise: Stumble*	Accel. or Cruise: Surge*	Accel. or Cruise: Stall	Backfire*
	Start Time (sec.)	5.0											
	Restart (sec.)												
	Restart (sec.)												
	Restart (sec.)												
	Fast-Idle Cam		1300	20.1		T							
	Tap Th. (5 sec. from St.)N		1450	20.9	✓								
	(10 sec. from Start)Dr		900	15.9	✓								
0	PT (0-25): Lt. Th.	12"						✓					
0.1	Cruise (25 mph)							✓					
0.2	PT (25-35): Th. to FULL Detent	4"						✓					
0.3	WOT Accel. (0-35)							✓					
0.4	PT (10-25): Lt. Th.	12"						✓					
0.5	Idle (30 sec.): Dr		690	16.5	✓								
	PT (0-25): Lt. Th.	12"						✓					
0.6	Cruise (25 mph)							✓					
0.7	PT (25-35): Th. to FULL Detent	4"						✓					
0.8	WOT Accel. (0-35)							✓					
0.9	PT (10-25): Lt. Th.	12"						✓					
1.0	Idle (30 sec.): Dr		690	16.2	✓								
	PT (0-25): Lt. Th.	12"						✓					
1.1	Cruise (25 mph)							✓					
1.2	PT (25-35): Th. to FULL Detent	4"						✓					
1.3	WOT Accel. (0-35)							✓					
1.4	PT (10-25): Lt. Th.	12"						✓					
1.5	Idle (30 sec.): Dr		700	16.2	✓								
	PT (0-45): Const. Vac.	12"						✓					
1.9	PT (25-35): Th. to FULL Detent	4"							T				
2.0	WOT Accel. (0-35)							✓					
2.1	PT (10-25): Lt. Th.	12"						✓					
2.2	Idle (30 sec.): Dr		700	16.2	✓								
	PT (0-45): Const. Vac.	12"						✓					
2.6	PT (25-35): Th. to FULL Detent	4"						✓					
2.7	WOT Accel. (0-35)							✓					
2.8	PT (10-25): Lt. Th.	12"						✓					

License 735 CPV N.5

S#3 1975 NOVA #20

Cold Start-Driveaway

Start Miles	T#4 Mode	Idle					Acceleration					Backfire*
		Engine Speed rpm	Intake Vacuum in. Hg	Satis.	Rough*	Stall	Satis.	Hesit.*	Stumble*	Surge*	Stall	
	PT (0-45): Const. Vac. 12"						✓					
3.3	PT (25-35): Th. to Detent Full	4"					✓					
3.4	WOT Accel. (0-35)						✓					
3.5	PT (10-25): Lt. Th. 12"						✓					
3.6	Idle (30 sec.): Dr	700	16.2	✓								
	PT (0-45): Const. Vac. 12"						✓					
4.0	PT (25-35): Th. to Detent Full	4"					✓					
4.1	WOT Accel. (0-35)						✓					
4.2	PT (10-25): Lt. Th. 12"						✓					
4.3	Idle (30 sec.): Dr	700	16.2	✓								
	PT (0-45): Const. Vac. 12"						✓					
4.7	PT (25-35): Th. to Detent Full	4"					✓					
4.8	WOT Accel. (0-35)						✓					
4.9	PT (10-25): Lt. Th. 12"						✓					
5.0	Idle (30 sec.): Dr	700	16.2	✓								
	PT (0-45): Const. Vac. 12"						✓					
5.4	PT (25-35): Th. to Detent Full	4"					✓					
5.5	WOT Accel. (0-35)						✓					
5.6	PT (10-25): Lt. Th. 12"						✓					
5.7	Idle (30 sec.): Dr	700	16.2	✓								
	PT (0-45): Const. Vac. 12"						✓					
6.1	PT (25-35): Th. to Detent Full	4"					✓					
6.2	WOT Accel. (0-35)						✓					
6.3	PT (10-25): Lt. Th. 12"						✓					
6.4	Idle (30 sec.): Dr	700	16.2	✓								

* T - Trace; M - Moderate; H - Heavy

Comments: ______________________________

License 735 CPV N.S

S#4 1975 NOVA #20

Warm Vehicle Evaluation

T#4 Mode		Accel. or Tip-In					Road Load			Idle					Backfire*
		Satis.	Hesit.*	Stumble*	Surge*	Stall	Satis.	Stretchy	Surge*	Engine rpm	Vacuum in. Hg	Satis.	Rough*	Stall	
Idle	N									890	18.9	✓			
	Dr									690	16.0	✓			
WOT Against T.C.		✓													
Road Load	20 mph						✓								
	30 mph						✓								
	40 mph						✓								
	50 mph						✓								
	60 mph														
	~~70 mph~~														
WOT Accel. (0-30)	Sudden	✓													
	Moderate	✓													
	Slow	✓													
PT Accel. (0-30)	1/4 Th.	✓													
	1/2 Th.	✓													
	3/4 Th.	✓													
2U PT Crowd (Min.-60 or Max.)	14 in.Hg														
	12 in.Hg	✓													
	10 in.Hg	✓													
	8 in.Hg	✓													
	6 in.Hg	✓													
PT Tip-In (Top Gear)	From 20	✓													
	From 30	✓													

50TO60 T SURGE

12'
9'
6"
20MP.H. MAX

0-60 mph WOT Acceleration (sec.) 8.5

Drive 5 miles at 60 mph; Idle 30 sec.; Soak 15 min.
After soak, start according to manufacturer's hot-start procedure; Return to Idle

Start Time (sec.)	4.0	Idle in Neutral (60 sec.)	700	17.0	✓			
Restart (sec.)								
Restart (sec.)								
Restart (sec.)								

Comments:

Proposed CRC
Driveability Test
Sheet 1 of 4

Date 10/11/75
Test Number 1
Fuel CK #29552-D-2

#I

Test Vehicle

Make CHEVROLET
Model NOVA #26
Year 1975
Transmission TURBO HYDRAMATIC
A/C NO PB NO PS YES
License No. 735 CPV. N.J

Engine Type V-8
Displacement 350 CID
Nominal C.R. 8.5
Carb. Make ROCHESTER No. Bbls. 4
Emission Control System CALF
Odometer: Start 13790 Finish 13813

Weather

C.T.R ROOM ~~Ambient~~ Temp.: Start 70 °F
Finish 69 °F

Observed Barom.: Start 30.20 in. Hg
Finish 30.19 in. Hg

Relative Humidity: Start ____ % 69-60
Finish ____ % 68-57

CLAYTON ~~Road Conditions~~: Wet ____
Dry ✓

Time: Start 8:30
Finish 9:45

Soak Time (hrs.) 16 HRS
Soak Temp. (°F) 70°

Test Crew

Driver WESLEY HOWARTH
Recorder SAMUEL IRWIN

Observers JOHN FOWLKS

Remarks

License 735CPV

#2 1975 NOVA #26

Cold Start-Driveaway

Start Miles	T-#1 Mode		Idle					Accel. or Cruise					
			Engine Speed rpm	Intake Vacuum in. Hg	Satis.	Rough*	Stall	Satis.	Hesit.*	Stumble*	Surge*	Stall	Backfire*
	Start Time (sec.)	1.0											
	Restart (sec.)												
	Restart (sec.)												
	Restart (sec.)												
	Fast-Idle Cam		1300	20.0	✓								
	Tap Th. (5 sec. from St.)N		1500	21.0	✓								
	(10 sec. from Start)Dr		900	16.0	✓								
0	PT (0-25): Lt. Th. 12"							✓					
0.1	Cruise (25 mph)							✓					
0.2	PT (25-35): Th. to FULL Detent		4"					✓					
0.3	WOT Accel. (0-35)							✓					
0.4	PT (10-25): Lt. Th. 12"							✓					
0.5	Idle (30 sec.): Dr		650	16.5	✓								
	PT (0-25): Lt. Th. 12"							✓					
0.6	Cruise (25 mph)							✓					
0.7	PT (25-35): Th. to FULL Detent		4"					✓					
0.8	WOT Accel. (0-35)							✓					
0.9	PT (10-25): Lt. Th. 12"							✓					
1.0	Idle (30 sec.): Dr		675	16.5	✓								
	PT (0-25): Lt. Th. 12"							✓					
1.1	Cruise (25 mph)							✓					
1.2	PT (25-35): Th. to FULL Detent		4"					✓					
1.3	WOT Accel. (0-35)							✓					
1.4	PT (10-25): Lt. Th. 12"							✓					
1.5	Idle (30 sec.): Dr		675	16.5	✓								
	PT (0-45): Const. Vac. 12"							✓					
1.9	PT (25-35): Th. to FULL Detent		4"					✓					
2.0	WOT Accel. (0-35)							✓					
2.1	PT (10-25): Lt. Th. 12"							✓					
2.2	Idle (30 sec.): Dr		675	16.5	✓								
	PT (0-45): Const. Vac. 12"							✓					
2.6	PT (25-35): Th. to FULL Detent		4"					✓					
2.7	WOT Accel. (0-35)							✓					
2.8	PT (10-25): Lt. Th. 12"							✓					

License 735CPV N.S

#3 1975 NOVA #26

Cold Start-Driveaway

		Idle					Acceleration					
Start Miles	T#1 Mode	Engine Speed rpm	Intake Vacuum in. Hg	Satis.	Rough*	Stall	Satis.	Hesit.*	Stumble*	Surge*	Stall	Backfire*
	PT (0-45): Const. Vac. 12"						✓					
3.3	PT (25-35): Th. to Detent FULL	4"					✓					
3.4	WOT Accel. (0-35)						✓					
3.5	PT (10-25): Lt. Th. 12"						✓					
3.6	Idle (30 sec.): Dr	700	16.5	✓								
	PT (0-45): Const. Vac. 12"						✓					
4.0	PT (25-35): Th. to Detent FULL	4"					✓					
4.1	WOT Accel. (0-35)						✓					
4.2	PT (10-25): Lt. Th. 12"						✓					
4.3	Idle (30 sec.): Dr	700	16.5	✓								
	PT (0-45): Const. Vac. 12"						✓					
4.7	PT (25-35): Th. to Detent FULL	4"					✓					
4.8	WOT Accel. (0-35)						✓					
4.9	PT (10-25): Lt. Th. 12"						✓					
5.0	Idle (30 sec.): Dr	700	16.5	✓								
	PT (0-45): Const. Vac. 12"						✓					
5.4	PT (25-35): Th. to Detent FULL	4"					✓					
5.5	WOT Accel. (0-35)						✓					
5.6	PT (10-25): Lt. Th. 12"						✓					
5.7	Idle (30 sec.): Dr	700	16.5	✓								
	PT (0-45): Const. Vac. 12"						✓					
6.1	PT (25-35): Th. to Detent FULL	4"					✓					
6.2	WOT Accel. (0-35)						✓					
6.3	PT (10-25): Lt. Th. 12"						✓					
6.4	Idle (30 sec.): Dr	700	16.5	✓								

* T - Trace; M - Moderate; H - Heavy

Comments:

License 735 CPY NJ

#4 1975 NOVA #26

Warm Vehicle Evaluation

T#1 Mode		Accel. or Tip-In					Road Load			Idle					Backfire*
		Satis.	Hesit.*	Stumble*	Surge*	Stall	Satis.	Stretchy	Surge*	Engine rpm	Vacuum in. Hg	Satis.	Rough*	Stall	
Idle	N									880	19.1	✓			
	Dr									690	16.2	✓			
WOT Against T.C.		✓													
Road Load	20 mph						✓								
	30 mph						✓								
	40 mph						✓								
	50 mph						✓								
	60 mph						✓								
	~~70 mph~~														
WOT Accel. (0-30)	Sudden	✓													
	Moderate	✓													
	Slow	✓													
PT Accel. (0-30)	1/4 Th.	✓					12"								
	1/2 Th.	✓					9"								
	3/4 Th.	✓					6"								
PT Crowd (Min. 60 or Max.) 20TO60	14 in.Hg						MAX 20MPH								
	12 in.Hg	✓													
	10 in.Hg	✓													
	8 in.Hg	✓													
	6 in.Hg	✓													
PT Tip-In (Top Gear)	From 20	✓													
	From 30	✓													

0-60 mph WOT Acceleration (sec.) 8.4

Drive 5 miles at 60 mph; Idle 30 sec. N; Soak 15 min.
After soak, start according to manufacturer's hot-start procedure; Return to Idle

Start Time (sec.)	4.0	Idle in Neutral (60 sec.)	705	17.9	✓			
Restart (sec.)								
Restart (sec.)								
Restart (sec.)								

Comments:

Proposed CRC
Driveability Test
Sheet 1 of 4

Date 10/12/75
Test Number 3
Fuel CK #29551-D-3

Test Vehicle

Make CHEVROLET
Model NOVA #26
Year 1975
Transmission TURBO HYDRAMATIC
A/C NO PB NO PS YES
License No. 735 CPV N.J.

Engine Type V-8
Displacement 350 CID
Nominal C.R. 8.5
Carb. Make ROCHESTAR No. Bbls. 4
Emission Control System CAL
Odometer: Start 13832 Finish 13857

Weather

CTR. ^
~~Ambient~~ Temp.: Start 70 °F
Finish 69 °F
Observed Barom.: Start 30.05 in. Hg
Finish 30.03 in. Hg
Relative Humidity: Start ____ % 70-60
Finish ____ % 68-58

CLAYTON
~~Road Conditions: Wet~~ ____
Dry ____
Time: Start 8:55
Finish 10:05
Soak Time (hrs.) 16 HR
Soak Temp. (°F) 70

Test Crew

Driver WESLEY HOWARTH
Recorder SAMUEL IRWIN

Observers GEORGE BARNES

Remarks

Reproduced from best available copy.

License 735 CPV N.J
S#2
1975 NOVA #26

Cold Start-Driveaway

Start Miles	T#3 Mode		Idle					Accel. or Cruise					
			Engine Speed rpm	Intake Vacuum in. Hg	Satis.	Rough*	Stall	Satis.	Hesit.*	Stumble*	Surge*	Stall	Backfire*
	Start Time (sec.)	2.0											
	Restart (sec.)												
	Restart (sec.)												
	Restart (sec.)												
	Fast-Idle Cam		1150	19.0	✓								
	Tap Th. (5 sec. from St.)N		1350	20.2	✓								
	(10 sec. from Start)Dr		900	15.5	✓								
0	PT (0-25): Lt. Th. 12"							✓					
0.1	Cruise (25 mph)							✓					
0.2	PT (25-35): Th. to FULL Detent 4"								✓				✓
0.3	WOT Accel. (0-35)											✓	
0.4	PT (10-25): Lt. Th. 12"							✓					
0.5	Idle (30 sec.): Dr		680	16.2	✓								
	PT (0-25): Lt. Th. 12"							✓					
0.6	Cruise (25 mph)							✓					
0.7	PT (25-35): Th. to FULL Detent 4"							✓					
0.8	WOT Accel. (0-35)							✓					
0.9	PT (10-25): Lt. Th. 12"							✓					
1.0	Idle (30 sec.): Dr		690	16.0	✓								
	PT (0-25): Lt. Th. 12"							✓					
1.1	Cruise (25 mph)							✓					
1.2	PT (25-35): Th. to FULL Detent 4"							✓					
1.3	WOT Accel. (0-35)							✓					
1.4	PT (10-25): Lt. Th. 12"							✓					
1.5	Idle (30 sec.): Dr		690	16.0	✓								
	PT (0-45): Const. Vac. 12"							✓					
1.9	PT (25-35): Th. to FULL Detent 4"							✓					
2.0	WOT Accel. (0-35)							✓					
2.1	PT (10-25): Lt. Th. 12"							✓					
2.2	Idle (30 sec.): Dr		690	16.0	✓								
	PT (0-45): Const. Vac. 12"								M	T			
2.6	PT (25-35): Th. to FULL Detent 4"							✓					
2.7	WOT Accel. (0-35)							✓					
2.8	PT (10-25): Lt. Th. 12"							✓					

S#3

License 735 CPV N.J
1975 NOVA #26

Cold Start-Driveaway

Start Miles	T#3 Mode	Idle					Acceleration					Backfire*
		Engine Speed rpm	Intake Vacuum in. Hg	Satis.	Rough*	Stall	Satis.	Hesit.*	Stumble*	Surge*	Stall	
	PT (0-45): Const. Vac. 12"						✓					
3.3	PT (25-35): Th. to Detent FULL	4"					✓					
3.4	WOT Accel. (0-35)						✓					
3.5	PT (10-25): Lt. Th. 12"						✓					
3.6	Idle (30 sec.): Dr	690	16.0	✓								
	PT (0-45): Const. Vac. 12"						✓					
4.0	PT (25-35): Th. to Detent FULL	4"					✓					
4.1	WOT Accel. (0-35)						✓					
4.2	PT (10-25): Lt. Th. 12"						✓					
4.3	Idle (30 sec.): Dr	690	16.0	✓								
	PT (0-45): Const. Vac. 12"						✓					
4.7	PT (25-35): Th. to Detent FULL	4"					✓					
4.8	WOT Accel. (0-35)						✓					
4.9	PT (10-25): Lt. Th. 12"						✓					
5.0	Idle (30 sec.): Dr	690	16.0	✓								
	PT (0-45): Const. Vac. 12"						✓					
5.4	PT (25-35): Th. to Detent FULL	4"					✓					
5.5	WOT Accel. (0-35)						✓					
5.6	PT (10-25): Lt. Th. 12"						✓					
5.7	Idle (30 sec.): Dr	690	16.0	✓								
	PT (0-45): Const. Vac. 12"						✓					
6.1	PT (25-35): Th. to Detent FULL	4"					✓					
6.2	WOT Accel. (0-35)						✓					
6.3	PT (10-25): Lt. Th. 12"						✓					
6.4	Idle (30 sec.): Dr	690	16.0	✓								

* T - Trace; M - Moderate; H - Heavy

Comments:

License 735CPV N.J

Warm Vehicle Evaluation

S#4 1975 NOVA #26

T#3 Mode		Accel. or Tip-In					Road Load			Idle					Backfire*	
		Satis.	Hesit.*	Stumble*	Surge*	Stall	Satis.	Stretchy	Surge*	Engine rpm	Vacuum in. Hg	Satis.	Rough*	Stall		
Idle	N									890	18.7	✓				
	Dr									690	15.9	✓				
WOT Against T.C.		✓														
Road Load	20 mph						✓									
	30 mph						✓									
	40 mph						✓									
	50 mph						✓									
	60 mph								T							50TO60T SURGE
	~~70 mph~~															
WOT Accel. (0-30)	Sudden	✓														
	Moderate	✓														
	Slow	✓														
PT Accel. (0-30)	1/4 Th.	✓														12"
	1/2 Th.	✓														9'
	3/4 Th.	✓														6"
PT Crowd 20 (Min. 60 or Max.)	14 in.Hg															MAX 20MPH
	12 in.Hg	✓														
	10 in.Hg	✓														
	8 in.Hg	✓														
	6 in.Hg	✓														
PT Tip-In (Top Gear)	From 20	✓														
	From 30	✓														

0-60 mph WOT Acceleration (sec.) 8.4

Drive 5 miles at 60 mph; Idle 30 sec.; Soak 15 min.
After soak, start according to manufacturer's hot-start procedure; Return to Idle

Start Time (sec.)	5.0	Idle in Neutral (60 sec.)	750	18.1		T		
Restart (sec.)								
Restart (sec.)								
Restart (sec.)								

Comments:

Date 10/11/75
Test Number 2
Fuel CK 29573-D4-1

Proposed CRC
Driveability Test
Sheet 1 of 4

S#I

Test Vehicle

Make CHEVROLET
Model NOVA #26
Year 1975
Transmission TURBO HYDRAMATIC
A/C NO PB NO PS YES
License No. 735 CPV N.S

Engine Type V-8
Displacement 350CID
Nominal C.R. 8.5
Carb. Make ROCHESTER No. Bbls. 4
Emission Control System CALF.
Odometer: Start 13813 Finish 13832

Weather

C.T.R. ROOM ~~Ambient~~ Temp.: Start 70 °F
Finish 70 °F
Observed Barom.. Start 30.19 in. Hg
Finish 30.10 in. Hg
Relative Humidity: Start ____ % 69-60
Finish ____ % 71-61

CLAYTON ~~Road Conditions: Wet~~ ____
Dry ____
Time: Start 1815
Finish 2:30
Soak Time (hrs.) 2 HRS
Soak Temp. (°F) 70

Test Crew

Driver WESLEY HOWARTH
Recorder SAMUEL IRWIN

Observers JOHN FOWLKS

Remarks

T-2 License 735 C PV N5
S#2 NOVA 1975 #26

Cold Start-Driveaway

Start Miles	T#2 Mode		Idle: Engine Speed rpm	Idle: Intake Vacuum in. Hg	Idle: Satis.	Idle: Rough*	Idle: Stall	Accel. or Cruise: Satis.	Accel. or Cruise: Hesit.*	Accel. or Cruise: Stumble*	Accel. or Cruise: Surge*	Accel. or Cruise: Stall	Backfire*
	Start Time (sec.)	1.0											
	Restart (sec.)												
	Restart (sec.)												
	Restart (sec.)												
	Fast-Idle Cam		1200	20.0	✓								
	Tap Th. (5 sec. from St.)N		1400	20.5	✓								
	(10 sec. from Start)Dr		900	16.0	✓								
0	PT (0-25): Lt. Th.	12"						✓					
0.1	Cruise (25 mph)							✓					
0.2	PT (25-35): Th. to FULL Detent	4						✓					
0.3	WOT Accel. (0-35)							✓					
0.4	PT (10-25): Lt. Th.	12"						✓					
0.5	Idle (30 sec.): Dr		675	16.2		T							
	PT (0-25): Lt. Th.	12"						✓					
0.6	Cruise (25 mph)							✓					
0.7	PT (25-35): Th. to FULL Detent	4"						✓					
0.8	WOT Accel. (0-35)									✓			✓
0.9	PT (10-25): Lt. Th.	12"						✓					
1.0	Idle (30 sec.): Dr		690	16.0	✓								
	PT (0-25): Lt. Th.	12"						✓					
1.1	Cruise (25 mph)							✓					
1.2	PT (25-35): Th. to FULL Detent	4"						✓					
1.3	WOT Accel. (0-35)							✓					
1.4	PT (10-25): Lt. Th.	12"						✓					
1.5	Idle (30 sec.): Dr		700	16.0	✓								
	PT (0-45): Const. Vac.	12"						✓					
1.9	PT (25-35): Th. to FULL Detent	4"						✓					
2.0	WOT Accel. (0-35)							✓					
2.1	PT (10-25): Lt. Th.	12"						✓					
2.2	Idle (30 sec.): Dr		700	16.0	✓								
	PT (0-45): Const. Vac.	12"						✓					
2.6	PT (25-35): Th. to FULL Detent	4"						✓					
2.7	WOT Accel. (0-35)							✓					
2.8	PT (10-25): Lt. Th.	12"											

License 735 C PV N.J

T#2
S#3
NOVA 1975 #86

Cold Start-Driveaway

Start Miles	T #2 Mode	Idle					Acceleration					Backfire*
		Engine Speed rpm	Intake Vacuum in. Hg	Satis.	Rough*	Stall	Satis.	Hesit.*	Stumble*	Surge*	Stall	
	PT (0-45): Const. Vac. 12"						✓					
3.3	PT (25-35): Th. to FULL Detent	4"					✓					
3.4	WOT Accel. (0-35)						✓					
3.5	PT (10-25): Lt. Th. 12"						✓					
3.6	Idle (30 sec.): Dr	690	16.0	✓								
	PT (0-45): Const. Vac. 12"						✓					
4.0	PT (25-35): Th. to FULL Detent	4"					✓					
4.1	WOT Accel. (0-35)						✓					
4.2	PT (10-25): Lt. Th. 12"						✓					
4.3	Idle (30 sec.): Dr	700	16.1	✓								
	PT (0-45): Const. Vac. 12"						✓					
4.7	PT (25-35): Th. to FULL Detent	4"					✓					
4.8	WOT Accel. (0-35)						✓					
4.9	PT (10-25): Lt. Th. 12"						✓					
5.0	Idle (30 sec.): Dr	700	16.2	✓								
	PT (0-45): Const. Vac. 12"						✓					
5.4	PT (25-35): Th. to FULL Detent	4"					✓					
5.5	WOT Accel. (0-35)						✓					
5.6	PT (10-25): Lt. Th. 12"						✓					
5.7	Idle (30 sec.): Dr	700	16.2	✓								
	PT (0-45): Const. Vac. 12"						✓					
6.1	PT (25-35): Th. to FULL Detent	4"					✓					
6.2	WOT Accel. (0-35)						✓					
6.3	PT (10-25): Lt. Th. 12"						✓					
6.4	Idle (30 sec.): Dr	700	16.1	✓								

* T - Trace; M - Moderate; H - Heavy

Comments: ____________________

T-2
5#4

License 735 CPV NJ
NOVA 1975-#26

Warm Vehicle Evaluation

T#2 Mode		Accel. or Tip-In					Road Load			Idle					Backfire*
		Satis.	Hesit.*	Stumble*	Surge*	Stall	Satis.	Stretchy	Surge*	Engine rpm	Vacuum in. Hg	Satis.	Rough*	Stall	
Idle	N									850	18.5	✓			
	Dr									680	16.0	✓			
WOT Against T.C.		✓													
Road Load	20 mph						✓								
	30 mph						✓								
	40 mph						✓								
	50 mph								M	50TO60SURGE					
	60 mph						✓								
	~~70 mph~~														
WOT Accel. (0-30)	Sudden	✓													
	Moderate	✓													
	Slow	✓													
PT Accel. (0-30)	1/4 Th.	✓					13"								
	1/2 Th.	✓					9"								
	3/4 Th.	✓					6"								
PT Crowd (Min.-60 or Max.)	14 in.Hg						20 M.P.R. MAX								
	12 in.Hg	✓													
	10 in.Hg	✓													
	8 in.Hg	✓													
	6 in.Hg	✓													
PT Tip-In (Top Gear)	From 20	✓													
	From 30	✓													

0-60 mph WOT Acceleration (sec.) 9.4

Drive 5 miles at 60 mph; Idle 30 N sec.; Soak 15 min.
After soak, start according to manufacturer's hot-start procedure; Return to Idle

Start Time (sec.)	4.0	Idle in Neutral (60 sec.)	700	17.9		T		
Restart (sec.)								
Restart (sec.)								
Restart (sec.)								

Comments:

Date 9/19/77
Test Number 1
Fuel D-1

Proposed CRC
Driveability Test
Sheet 1 of 4

Test Vehicle

Make NOVA
Model 2 door sedan
Year 1975
Transmission automatic
A/C NO PB ____ PS ____
License No. EPA 509

Engine Type V/8
Displacement 350 cu. in.
Nominal C.R. 9; 1
Carb. Make Rochester No. Bbls. 4
Emission Control System stock - Knock sensor control
Odometer: Start 22480 Finish 22492

Weather

Ambient Temp.: Start 84 °F Finish ____ °F
Observed Barom.: Start 29.78 in. Hg Finish ____ in. Hg
Relative Humidity: Start ____ % Finish ____ %

Clayton #2
Road Conditions: Wet ____ Dry ____
Time: Start ____ Finish ____
Soak Time (hrs.) ____
Soak Temp. (°F) ____

Test Crew

Driver R. Flynn
Recorder R. Hoernner

Observers L. HURST

Remarks

Test No. 1
License EPA 509

Sheet 2 of 4

Cold Start-Driveaway

Start Miles	Mode	Idle: Engine Speed rpm	Idle: Intake Vacuum in. Hg	Idle: Satis.	Idle: Rough*	Idle: Stall	Accel. or Cruise: Satis.	Accel. or Cruise: Hesit.*	Accel. or Cruise: Stumble*	Accel. or Cruise: Surge*	Accel. or Cruise: Stall	Backfire*
	Start Time (sec.)											
	Restart (sec.)											
	Restart (sec.)											
	Restart (sec.)											
	Fast-Idle Cam	2250	20.5	✓								
	Tap Th. (5 sec. from St.)N	1800	20.5	✓								
	(10 sec. from Start)Dr	890	13.0	✓								
0	PT (0-25): Lt. Th.						✓					
0.1	Cruise (25 mph)						✓					
0.2	PT (25-35): Th. to Detent						✓					
0.3	WOT Accel. (0-35)						✓					
0.4	PT (10-25): Lt. Th.						✓					
0.5	Idle (30 sec.): Dr	1100	11.5		T ✓							
	PT (0-25): Lt. Th.						✓					
0.6	Cruise (25 mph)						✓					
0.7	PT (25-35): Th. to Detent						✓					
0.8	WOT Accel. (0-35)						✓					
0.9	PT (10-25): Lt. Th.						✓					
1.0	Idle (30 sec.): Dr	860	10.5		M ✓							
	PT (0-25): Lt. Th.						✓					
1.1	Cruise (25 mph)						✓					
1.2	PT (25-35): Th. to Detent						✓					
1.3	WOT Accel. (0-35)						✓					
1.4	PT (10-25): Lt. Th.						✓					
1.5	Idle (30 sec.): Dr	670	18.0	✓								
	PT (0-45): Const. Vac.						✓					
1.9	PT (25-35): Th. to Detent						✓					
2.0	WOT Accel. (0-35)						✓					
2.1	PT (10-25): Lt. Th.						✓					
2.2	Idle (30 sec.): Dr	660	18.0	✓								
	PT (0-45): Const. Vac.						✓					
2.6	PT (25-35): Th. to Detent						✓					
2.7	WOT Accel. (0-35)						✓					
2.8	PT (10-25): Lt. Th.								T			
2.9	Idle (30 sec.): Dr	665	18.0									

Test No. 2
License ERA 509

Cold Start-Driveaway

Start Miles	Mode	Idle: Engine Speed rpm	Idle: Intake Vacuum in. Hg	Idle: Satis.	Idle: Rough*	Idle: Stall	Acceleration: Satis.	Acceleration: Hesit.*	Acceleration: Stumble*	Acceleration: Surge*	Acceleration: Stall	Backfire*
	PT (0-45): Const. Vac.						✓					
3.3	PT (25-35): Th. to Detent						✓					
3.4	WOT Accel. (0-35)						✓					
3.5	PT (10-25): Lt. Th.						✓					
3.6	Idle (30 sec.): Dr	665	18.0	✓								
	PT (0-45): Const. Vac.						✓					
4.0	PT (25-35): Th. to Detent						✓					
4.1	WOT Accel. (0-35)						✓					
4.2	PT (10-25): Lt. Th.						✓					
4.3	Idle (30 sec.): Dr	665	18.0	✓								
	PT (0-45): Const. Vac.						✓					
4.7	PT (25-35): Th. to Detent						✓					
4.8	WOT Accel. (0-35)						✓					
4.9	PT (10-25): Lt. Th.						✓					
5.0	Idle (30 sec.): Dr	665	18.0	✓								
	PT (0-45): Const. Vac.						✓					
5.4	PT (25-35): Th. to Detent						✓					
5.5	WOT Accel. (0-35)						✓					
5.6	PT (10-25): Lt. Th.						✓					
5.7	Idle (30 sec.): Dr	665	18.0	✓								
	PT (0-45): Const. Vac.						✓					
6.1	PT (25-35): Th. to Detent						✓					
6.2	WOT Accel. (0-35)						✓					
6.3	PT (10-25): Lt. Th.						✓					
6.4	Idle (30 sec.): Dr	665	18.0	✓								

* T - Trace; M - Moderate; H - Heavy

Comments: ____________________

Test No. 1
License EPA 509

Sheet 4 of 4

Warm Vehicle Evaluation

Mode		Accel. or Tip-In					Road Load			Idle					Backfire*
		Satis.	Hesit.*	Stumble*	Surge*	Stall	Satis.	Stretchy	Surge*	Engine rpm	Vacuum in. Hg	Satis.	Rough*	Stall	
Idle	N									925	21.0				
	Dr									675	17.5				
WOT Against T.C.		✓													
Road Load	20 mph						✓								
	30 mph						✓								
	40 mph						✓								
	50 mph								T						
	60 mph								T						
	~~70 mph~~														
WOT Accel. (0-30)	Sudden	✓													
	Moderate	✓													
	Slow	✓					12"								
PT Accel. (0-30)	1/4 Th.	✓					9"								
	1/2 Th.	✓					6"								
	3/4 Th.	✓													
20-60 PT Crowd (Min.-70 or Max.)	14 in.Hg	max	25	mph											
	12 in.Hg	✓													
	10 in.Hg	✓													
	8 in.Hg	✓													
	6 in.Hg	✓													
PT Tip-In (Top Gear)	From 20	✓													
	From 30	✓													

0-~~70~~60 mph WOT Acceleration (sec.) 23.8

Drive 5 miles at 70 mph; Idle 30 sec.; Soak 15 min.
After soak, start according to manufacturer's hot-start procedure; Return to Idle

Start Time (sec.)	1.5	Idle in Neutral (60 sec.)	960	21.0				
Restart (sec.)								
Restart (sec.)								
Restart (sec.)								

Comments:

Date 9/22/77
Test Number 2
Fuel D-2

Proposed CRC
Driveability Test
Sheet 1 of 4

Test Vehicle

Make CHevy NOVA
Model 2 door sedan
Year 1975
Transmission Automatic
A/C NO PB NO PS yes
License No. EPA 509

Engine Type V-8
Displacement 350
Nominal C.R. 9:1
Carb. Make Roch. No. Bbls. 4
Emission Control System stock
Odometer: Start 22550 Finish 22560

Weather

Ambient Temp.: Start 69 °F
Finish ____ °F
Observed Barom.: Start 30.17 in. Hg
Finish ____ in. Hg
Relative Humidity: Start 76 %
Finish ____ %

~~Road Conditions~~ Clayton #2: Wet ____
Dry ____
Time: Start ____
Finish ____
Soak Time (hrs.) ____
Soak Temp. (°F) ____

Test Crew

Driver R. Flynn
Recorder R. Hoerner

Observers L. Hurst

Remarks

Knock sensor control in operation - NO response observed during Test.

Test No. 2
License EPA 509

Sheet 2 of 4

Cold Start-Driveaway

Start Miles	Mode		Idle					Accel. or Cruise					Backfire*
			Engine Speed rpm	Intake Vacuum in. Hg	Satis.	Rough*	Stall	Satis.	Hesit.*	Stumble*	Surge*	Stall	
	Start Time (sec.)	1,0											
	Restart (sec.)	Total start	Very Hard start										
	Restart (sec.)	Time 2	4 attempts needed To start										
	Restart (sec.)	1.5 min											
	Fast-Idle Cam		2500	22.0	✓								
	Tap Th. (5 sec. from St.)N		2250	22.0	✓								
	(10 sec. from Start)Dr		940	14.0		T							
0	PT (0-25): Lt. Th.							✓					
0.1	Cruise (25 mph)							✓					
0.2	PT (25-35): Th. to Detent							✓					
✓ 0.3	WOT Accel. (0-35)							✓					
0.4	PT (10-25): Lt. Th.							✓					
0.5	Idle (30 sec.): Dr		680	18.8	✓								
	PT (0-25): Lt. Th.							✓					
0.6	Cruise (25 mph)							✓					
0.7	PT (25-35): Th. to Detent							✓					
✓ 0.8	WOT Accel. (0-35)							✓					
0.9	PT (10-25): Lt. Th.							✓					
1.0	Idle (30 sec.): Dr		690	18.5	✓								
	PT (0-25): Lt. Th.							✓					
1.1	Cruise (25 mph)							✓					
✓ 1.2	PT (25-35): Th. to Detent							✓					
1.3	WOT Accel. (0-35)							✓					
1.4	PT (10-25): Lt. Th.							✓					
1.5	Idle (30 sec.): Dr		685	18.5	✓								
	PT (0-45): Const. Vac.							✓					
1.9	PT (25-35): Th. to Detent							✓					
✓ 2.0	WOT Accel. (0-35)							✓					
2.1	PT (10-25): Lt. Th.							✓					
2.2	Idle (30 sec.): Dr		685	18.5	✓								
	PT (0-45): Const. Vac.							✓					
2.6	PT (25-35): Th. to Detent							✓					
2.7	WOT Accel. (0-35)							✓					
2.8	PT (10-25): Lt. Th.							✓					
2.9	Idle (30 sec.): Dr		685	18.5	✓								

Test No. 2
License ERA 509

Cold Start-Driveaway

Start Miles	Mode	Idle					Acceleration					Backfire*
		Engine Speed rpm	Intake Vacuum in. Hg	Satis.	Rough*	Stall	Satis.	Hesit.*	Stumble*	Surge*	Stall	
	PT (0-45): Const. Vac.						✓					
3.3	PT (25-35): Th. to Detent						✓					
✓ 3.4	WOT Accel. (0-35)						✓					
3.5	PT (10-25): Lt. Th.									T		
3.6	Idle (30 sec.): Dr	680	18.5	✓								
	PT (0-45): Const. Vac.						✓					
4.0	PT (25-35): Th. to Detent						✓					
✓ 4.1	WOT Accel. (0-35)						✓					
4.2	PT (10-25): Lt. Th.									T		
4.3	Idle (30 sec.): Dr	675	18.5		T							
	PT (0-45): Const. Vac.						T					
4.7	PT (25-35): Th. to Detent						✓					
✓ 4.8	WOT Accel. (0-35)						✓					
4.9	PT (10-25): Lt. Th.						✓					
5.0	Idle (30 sec.): Dr	670	18.5	✓								
	PT (0-45): Const. Vac.							T				
5.4	PT (25-35): Th. to Detent						✓					
✓ 5.5	WOT Accel. (0-35)						✓					
5.6	PT (10-25): Lt. Th.						✓					
5.7	Idle (30 sec.): Dr	665	18.5	✓								
	PT (0-45): Const. Vac.									T		
6.1	PT (25-35): Th. to Detent						✓					
✓ 6.2	WOT Accel. (0-35)						✓					
6.3	PT (10-25): Lt. Th.						✓					
6.4	Idle (30 sec.): Dr	665	18.5	✓								

* T - Trace; M - Moderate; H - Heavy

Comments: No Response from Knock Sensor

Test No. 2
License EPA 509

Sheet 4 of 4

Warm Vehicle Evaluation

Mode		Accel. or Tip-In					Road Load			Idle					Backfire*
		Satis.	Hesit.*	Stumble*	Surge*	Stall	Satis.	Stretchy	Surge*	Engine rpm	Vacuum in. Hg	Satis.	Rough*	Stall	
Idle	N									900	21				
	Dr									650	18.0				
WOT Against T.C.					T										
Road Load	20 mph						✓								
	30 mph								T						
	40 mph						✓								
	50 mph						✓								
	60 mph								T						
	~~70 mph~~														
WOT Accel. (0-30)	Sudden	✓													
	Moderate	✓													
	Slow	✓													
PT Accel. (0-30)	1/4 Th.				T		12'								
	1/2 Th.	✓					9"								
	3/4 Th.	✓					6"								
PT Crowd 20 (Min.-60 or Max.)	14 in.Hg	max speed 23 mph													
	12 in.Hg	✓													
	10 in.Hg				T										
	8 in.Hg				T										
	6 in.Hg				T										
PT Tip-In (Top Gear)	From 20	✓													
	From 30	✓													

0-60 mph WOT Acceleration (sec.) 20.6

Drive 5 miles at 70 mph; Idle 30 sec.; Soak 15 min.
After soak, start according to manufacturer's hot-start procedure; Return to Idle

Start Time (sec.) 1.0		Idle in Neutral (60 sec.)	850	20.5					
Restart (sec.)									
Restart (sec.)									
Restart (sec.)									

Comments:

Date 9/26/77
Test Number 3
Fuel D-3

Proposed CRC
Driveability Test
Sheet 1 of 4

Test Vehicle

Make CHevy
Model NOVA
Year 1975
Transmission Auto
A/C NO PB NO PS yes
License No. EPA 509

Engine Type V-8
Displacement 350 cu. in.
Nominal C.R. 9:1
Carb. Make Rochester No. Bbls. 4
Emission Control System STOCK - Knock Sensor
Odometer: Start 22,594 Finish 22,602

Weather

Ambient Temp.: Start 77 °F
Finish ___ °F
Observed Barom.: Start 29.66 in. Hg
Finish ___ in. Hg
Relative Humidity: Start 87 %
Finish ___ %

Clayton #2
~~Road Conditions:~~ Wet ___
Dry ___
Time: Start ___
Finish ___
Soak Time (hrs.) ___
Soak Temp. (°F) ___

Test Crew

Driver R. Flynn
Recorder R. Hoernner

Observers L. Hurst

Remarks

Test No. 3
License EPA 509

Sheet 2 of 4

Cold Start-Driveaway

Start Miles	Mode		Idle					Accel. or Cruise					Backfire*
			Engine Speed rpm	Intake Vacuum in. Hg	Satis.	Rough*	Stall	Satis.	Hesit.*	Stumble*	Surge*	Stall	
	Start Time (sec.)	1.0											
	Restart (sec.)												
	Restart (sec.)												
	Restart (sec.)												
	Fast-Idle Cam		2250	21.0									
	Tap Th. (5 sec. from St.)N		1750	20.5		T							
	(10 sec. from Start)Dr		1250	18.0			6	would idle but stall when put in drive					1
0	PT (0-25): Lt. Th.		10" wouldn't make 25 @ 12"							T			
0.1	Cruise (25 mph)							✓					
0.2	PT (25-35): Th. to Detent							✓					
0.3	WOT Accel. (0-35)							✓					
0.4	PT (10-25): Lt. Th.		10" wouldn't make 25 @12"						T				
0.5	Idle (30 sec.): Dr		655	17.5	✓								
	PT (0-25): Lt. Th.									T			
0.6	Cruise (25 mph)							✓					
0.7	PT (25-35): Th. to Detent							✓					
0.8	WOT Accel. (0-35)							✓					
0.9	PT (10-25): Lt. Th.							✓					
1.0	Idle (30 sec.): Dr		645	17.5	✓								
	PT (0-25): Lt. Th.										T		
1.1	Cruise (25 mph)							✓					
1.2	PT (25-35): Th. to Detent							✓					
1.3	WOT Accel. (0-35)							✓					
1.4	PT (10-25): Lt. Th.							✓					
1.5	Idle (30 sec.): Dr		645	17.5	✓								
	PT (0-45): Const. Vac.							✓					
1.9	PT (25-35): Th. to Detent							✓					
2.0	WOT Accel. (0-35)							✓					
2.1	PT (10-25): Lt. Th.										T		
2.2	Idle (30 sec.): Dr		645	17.5	✓								
	PT (0-45): Const. Vac.							✓					
2.6	PT (25-35): Th. to Detent							✓					
2.7	WOT Accel. (0-35)							✓					
2.8	PT (10-25): Lt. Th.							✓					
2.9	Idle (30 sec.): Dr		665	18.0	✓								

Test No. 3
License EPA 509

Sheet 3 of 4

Cold Start-Driveaway

Start Miles	Mode	Idle					Acceleration					Backfire*
		Engine Speed rpm	Intake Vacuum in. Hg	Satis.	Rough*	Stall	Satis.	Hesit.*	Stumble*	Surge*	Stall	
	PT (0-45): Const. Vac.						✓					
3.3	PT (25-35): Th. to Detent						✓					
3.4	WOT Accel. (0-35)						✓					
3.5	PT (10-25): Lt. Th.						✓					
3.6	Idle (30 sec.): Dr	660	18.0	✓								
	PT (0-45): Const. Vac.						✓					
4.0	PT (25-35): Th. to Detent						✓					
4.1	WOT Accel. (0-35)						✓					
4.2	PT (10-25): Lt. Th.									T		
4.3	Idle (30 sec.): Dr	670	18.0	✓								
	PT (0-45): Const. Vac.						✓					
4.7	PT (25-35): Th. to Detent						✓					
4.8	WOT Accel. (0-35)						✓					
4.9	PT (10-25): Lt. Th.						✓					
5.0	Idle (30 sec.): Dr	665	18.0	✓								
	PT (0-45): Const. Vac.						✓					
5.4	PT (25-35): Th. to Detent						✓					
5.5	WOT Accel. (0-35)						✓					
5.6	PT (10-25): Lt. Th.						✓					
5.7	Idle (30 sec.): Dr	660	18.0	✓								
	PT (0-45): Const. Vac.									T		
6.1	PT (25-35): Th. to Detent						✓					
6.2	WOT Accel. (0-35)						✓					
6.3	PT (10-25): Lt. Th.									T		
6.4	Idle (30 sec.): Dr	660	18.0	✓								

* T - Trace; M - Moderate; H - Heavy

Comments: No Response from Knock sensor during cold start driveaway.

Test No. 3
License EPA-509

Sheet 4 of 4

Warm Vehicle Evaluation

Mode		Accel. or Tip-In					Road Load			Idle					Backfire*
		Satis.	Hesit.*	Stumble*	Surge*	Stall	Satis.	Stretchy	Surge*	Engine rpm	Vacuum in. Hg	Satis.	Rough*	Stall	
Idle	N									920	21.0	✓			
	Dr									670	18.0	✓			
WOT Against T.C.				T	T										
Road Load	20 mph						✓								
	30 mph						✓								
	40 mph						✓								
	50 mph						✓								
	60 mph						✓								
	~~70 mph~~														
WOT Accel. (0-30)	Sudden	✓													
	Moderate	✓													
	Slow	✓													
PT Accel. (0-30)	1/4 Th.	✓					12"								
	1/2 Th.	✓					9"								
	3/4 Th.	✓					6'								
PT Crowd 20 ~~(Min. -70~~ 60 or Max.)	14 in.Hg	max	speed		23	mph									
	12 in.Hg	✓													
	10 in.Hg	✓													
	8 in.Hg	✓													
	6 in.Hg	✓													
PT Tip-In (Top Gear)	From 20	✓													
	From 30	✓													

0-~~70~~ 60 mph WOT Acceleration (sec.) 22.5

Drive 5 miles at 70 mph; Idle 30 sec.; Soak 15 min.
After soak, start according to manufacturer's hot-start procedure; Return to idle

Start Time (sec.)	1.8	Idle in Neutral (60 sec.)	800	20.0				
Restart (sec.)								
Restart (sec.)								
Restart (sec.)								

Comments: No Response from Knock sensor.

Date 9-27-77
Test Number 4
Fuel D-4-1

Proposed CRC
Driveability Test
Sheet 1 of 4

Test Vehicle

Make CHevy
Model NOVA
Year 1975
Transmission Auto
A/C NO PB NO PS yes
License No. EPA - 509

Engine Type V-8
Displacement 350
Nominal C.R. 9:1
Carb. Make Rochester No. Bbls. 4
Emission Control System Stock - Knock Sens
Odometer: Start 22,643 Finish

Weather

Ambient Temp.: Start 74 °F
Finish °F
Observed Barom.: Start 29.70 in. Hg
Finish in. Hg
Relative Humidity: Start 58 %
Finish %

Clayton # 2
~~Road Conditions~~: Wet X
Dry X
Time: Start
Finish
Soak Time (hrs.)
Soak Temp. (°F)

Test Crew

Driver R. Flynn
Recorder L. Hurst

Observers L. Hurst

Remarks

Test No. 4
License ERA-509

Sheet 2 of 4

Cold Start-Driveaway

Start Miles	Mode		Idle: Engine Speed rpm	Idle: Intake Vacuum In. Hg	Idle: Satis.	Idle: Rough*	Idle: Stall	Accel. or Cruise: Satis.	Accel. or Cruise: Hesit.*	Accel. or Cruise: Stumble*	Accel. or Cruise: Surge*	Accel. or Cruise: Stall	Backfire*
	Start Time (sec.)	1.0											
	Restart (sec.)												
	Restart (sec.)												
	Restart (sec.)												
	Fast-Idle Cam		2400	21.0									
	Tap Th. (5 sec. from St.)N		1500	19.0									
	(10 sec. from Start)Dr		920	11.0		M	1						
0	PT (0-25): Lt. Th.					10° R					T		
0.1	Cruise (25 mph)					10° Retard				T	T		
0.2	PT (25-35): Th. to Detent							✓					
0.3	WOT Accel. (0-35)							✓					
0.4	PT (10-25): Lt. Th.										T		
0.5	Idle (30 sec.): Dr		680	17.0	✓								
	PT (0-25): Lt. Th.										T		
0.6	Cruise (25 mph)							✓					
0.7	PT (25-35): Th. to Detent							✓					
0.8	WOT Accel. (0-35)							✓					
0.9	PT (10-25): Lt. Th.							✓					
1.0	Idle (30 sec.): Dr		680	17.0	✓								
	PT (0-25): Lt. Th.										T		
1.1	Cruise (25 mph)							✓					
1.2	PT (25-35): Th. to Detent							✓					
1.3	WOT Accel. (0-35)							✓					
1.4	PT (10-25): Lt. Th.							✓					
1.5	Idle (30 sec.): Dr		680	17.0	✓								
	PT (0-45): Const. Vac.							✓					
1.9	PT (25-35): Th. to Detent							✓					
2.0	WOT Accel. (0-35)							✓					
2.1	PT (10-25): Lt. Th.							✓					
2.2	Idle (30 sec.): Dr		680	17.0	✓								
	PT (0-45): Const. Vac.							✓					
2.6	PT (25-35): Th. to Detent							✓					
2.7	WOT Accel. (0-35)							✓					
2.8	PT (10-25): Lt. Th.							✓					
2.9	Idle (30 sec.): Dr		680	17.0									

Test No. 4
License EPA-509

Sheet 3 of 4

Cold Start-Driveaway

Start Miles	Mode	Idle					Acceleration					Backfire*
		Engine Speed rpm	Intake Vacuum in. Hg	Satis.	Rough*	Stall	Satis.	Hesit.*	Stumble*	Surge*	Stall	
	PT (0-45): Const. Vac.						✓					
3.3	PT (25-35): Th. to Detent						✓					
3.4	WOT Accel. (0-35)						✓					
3.5	PT (10-25): Lt. Th.						✓					
3.6	Idle (30 sec.): Dr	680	17.0	✓								
	PT (0-45): Const. Vac.						✓					
4.0	PT (25-35): Th. to Detent						✓					
4.1	WOT Accel. (0-35)						✓					
4.2	PT (10-25): Lt. Th.						✓					
4.3	Idle (30 sec.): Dr	680	17.0	✓								
	PT (0-45): Const. Vac.						✓					
4.7	PT (25-35): Th. to Detent						✓					
4.8	WOT Accel. (0-35)						✓					
4.9	PT (10-25): Lt. Th.									T		
5.0	Idle (30 sec.): Dr	700	17.0	✓								
	PT (0-45): Const. Vac.						✓					
5.4	PT (25-35): Th. to Detent						✓					
5.5	WOT Accel. (0-35)						✓					
5.6	PT (10-25): Lt. Th.						✓					
5.7	Idle (30 sec.): Dr	680	17.0	✓								
	PT (0-45): Const. Vac.						✓					
6.1	PT (25-35): Th. to Detent						✓					
6.2	WOT Accel. (0-35)						✓					
6.3	PT (10-25): Lt. Th.						✓					
6.4	Idle (30 sec.): Dr	680	17.0	✓								

* T - Trace; M - Moderate; H - Heavy

Comments: Knock Sensor only Responded in cold engine condition

Test No. 4
License EPA-509

Sheet 4 of 4

Warm Vehicle Evaluation

Mode		Accel. or Tip-In					Road Load			Idle					Backfire*
		Satis.	Hesit.*	Stumble*	Surge*	Stall	Satis.	Stretchy	Surge*	Engine rpm	Vacuum in. Hg	Satis.	Rough*	Stall	
Idle	N									990	20.5	✓			
	Dr									710	17.5	✓			
WOT Against T.C.		✓					Retard 4°								
Road Load	20 mph						✓								
	30 mph						✓								
	40 mph						✓								
	50 mph						✓								
	60 mph								T						
	~~70 mph~~														
WOT Accel. (0-30)	Sudden	✓													
	Moderate	✓													
	Slow	✓													
PT Accel. (0-30)	1/4 Th.	✓					12°								
	1/2 Th.	✓					9°								
	3/4 Th.	✓					6°								
PT Crowd (~~Min. 40~~ 20 60 or Max.)	14 in.Hg		Max	23	MPH										
	12 in.Hg	✓													
	10 in.Hg	✓													
	8 in.Hg	✓													
	6 in.Hg				T										
PT Tip-In (Top Gear)	From 20	✓													
	From 30	✓													

0-~~70~~ 60 mph WOT Acceleration (sec.) 22.4

Drive 5 miles at 70 mph; Idle 30 sec.; Soak 15 min.
After soak, start according to manufacturer's hot-start procedure; Return to Idle

Start Time (sec.)	1.0	Idle in Neutral (60 sec.)	850	19.5					
Restart (sec.)									
Restart (sec.)									
Restart (sec.)									

Comments:

Proposed CRC
Driveability Test
Sheet 1 of 4

Date 12/13/77
Test Number 1
Fuel D-1
After 4000 mi durability miles

Test Vehicle

Make CHevy
Model NOVA
Year 1975
Transmission Automatic 3-speed
A/C NO PB NO PS yess
License No. EPA - 509

Engine Type V-8
Displacement 350
Nominal C.R. 9:1.
Carb. Make Rochester No. Bbls. 4
Emission Control System standard
Odometer: Start 40,8550 Finish 40,867.8

Weather

Ambient Temp.: Start 74 °F
Finish 74 °F

Observed Barom.: Start 30.33 in. Hg
Finish 30.33 in. Hg

Relative Humidity: Start 54 %
Finish 54 %

Clayton #2 ~~Road Conditions~~: Wet ______
Dry ______

Time: Start ______
Finish ______

Soak Time (hrs.) ______
Soak Temp. (°F) ______

Test Crew

Driver R. Flynn
Recorder L. HURST

Observers ______

Remarks

Test No. ____________
License ____________

Sheet 2 of 4

Cold Start-Driveaway

Start Miles	Mode		Idle					Accel. or Cruise					Backfire*
			Engine Speed rpm	Intake Vacuum in. Hg	Satis.	Rough*	Stall	Satis.	Hesit.*	Stumble*	Surge*	Stall	
	Start Time (sec.)	1											
	Restart (sec.)												
	Restart (sec.)												
	Restart (sec.)												
	Fast-Idle Cam		2060	27.0									
	Tap Th. (5 sec. from St.)N		1500	20.0									
	(10 sec. from Start)Dr		990	12.0		T	1						
0	PT (0-25): Lt. Th. 12"								T				
0.1	Cruise (25 mph)							✓					
0.2	PT (25-35): Th. to Detent 4"							✓					
0.3	WOT Accel. (0-35) 4"							✓					
0.4	PT (10-25): Lt. Th. 12"							✓					
0.5	Idle (30 sec.): Dr		650	18.0	✓								
	PT (0-25): Lt. Th.							✓					
0.6	Cruise (25 mph)							✓					
0.7	PT (25-35): Th. to Detent							✓					
0.8	WOT Accel. (0-35)							✓					
0.9	PT (10-25): Lt. Th.							✓					
1.0	Idle (30 sec.): Dr		660	18.0	✓								
	PT (0-25): Lt. Th.							✓					
1.1	Cruise (25 mph)							✓					
1.2	PT (25-35): Th. to Detent							✓					
1.3	WOT Accel. (0-35)							✓					
1.4	PT (10-25): Lt. Th.							✓					
1.5	Idle (30 sec.): Dr		650	18.0	✓								
	PT (0-45): Const. Vac. 12"							✓					
1.9	PT (25-35): Th. to Detent							✓					
2.0	WOT Accel. (0-35)							✓					
2.1	PT (10-25): Lt. Th.							✓					
2.2	Idle (30 sec.): Dr		660	18.0	✓								
	PT (0-45): Const. Vac.							✓					
2.6	PT (25-35): Th. to Detent							✓					
2.7	WOT Accel. (0-35)							✓					
2.8	PT (10-25): Lt. Th.							✓					
2.9	Idle (30 sec.): Dr		660	18.0	✓								

[illegible] No. ____________
License ____________

Cold Start-Driveaway

Start Miles	Mode	Idle: Engine Speed rpm	Idle: Intake Vacuum in. Hg	Idle: Satis.	Idle: Rough*	Idle: Stall	Acceleration: Satis.	Acceleration: Hesit.*	Acceleration: Stumble*	Acceleration: Surge*	Acceleration: Stall	Backfire*
	PT (0-45): Const. Vac.						✓					
3.3	PT (25-35): Th. to Detent						✓					
3.4	WOT Accel. (0-35)						✓					
3.5	PT (10-25): Lt. Th.						✓					
3.6	Idle (30 sec.): Dr	660	18.0	✓								
	PT (0-45): Const. Vac.						✓					
4.0	PT (25-35): Th. to Detent						✓					
4.1	WOT Accel. (0-35)						✓					
4.2	PT (10-25): Lt. Th.						✓					
4.3	Idle (30 sec.): Dr	660	18.0	✓								
	PT (0-45): Const. Vac.						✓					
4.7	PT (25-35): Th. to Detent						✓					
4.8	WOT Accel. (0-35)						✓					
4.9	PT (10-25): Lt. Th.						✓					
5.0	Idle (30 sec.): Dr	650	18.0	✓								
	PT (0-45): Const. Vac.						✓					
5.4	PT (25-35): Th. to Detent						✓					
5.5	WOT Accel. (0-35)						✓					
5.6	PT (10-25): Lt. Th.						✓					
5.7	Idle (30 sec.): Dr	650	18.0	✓								
	PT (0-45): Const. Vac.						✓					
6.1	PT (25-35): Th. to Detent						✓					
6.2	WOT Accel. (0-35)						✓					
6.3	PT (10-25): Lt. Th.						✓					
6.4	Idle (30 sec.): Dr	650	18.0	✓								

* T - Trace; M - Moderate; H - Heavy

Comments: ____

Test No. ______________
License ______________

Sheet 4 of 4

Warm Vehicle Evaluation

Mode		Accel. or Tip-In					Road Load			Idle					Backfire*
		Satis.	Hesit.*	Stumble*	Surge*	Stall	Satis.	Stretchy	Surge*	Engine rpm	Vacuum in. Hg	Satis.	Rough*	Stall	
Idle	N									870	21.0				
	Dr									650	18.0				
WOT Against T.C.		✓													
Road Load	20 mph						✓								
	30 mph						✓								
	40 mph						✓								
	50 mph						✓								
	60 mph						✓								
	~~70 mph~~														
WOT Accel. (0-30)	Sudden	✓													
	Moderate	✓													
	Slow	✓													
PT Accel. (0-30)	1/4 Th.	✓					12"								
	1/2 Th.	✓					9"								
	3/4 Th.	✓					6'								
20-60 PT Crowd (Min.-70 or Max.)	14 in.Hg	✓													
	12 in.Hg	✓													
	10 in.Hg	✓													
	8 in.Hg	✓													
	6 in.Hg	✓													
PT Tip-In (Top Gear)	From 20	✓													
	From 30	✓													

0-~~70~~ 60 mph WOT Acceleration (sec.) 21.5

Drive 5 miles at 70 mph; Idle 30 sec.; Soak 15 min.
After soak, start according to manufacturer's hot-start procedure; Return to Idle

Start Time (sec.)	0.8	Idle in Neutral (60 sec.)	760	19.5				
Restart (sec.)								
Restart (sec.)								
Restart (sec.)								

Comments: ______________________________

6° BTC

Date 12-15-77
Test Number
Fuel D-2

Proposed CRC
Driveability Test
Sheet 1 of 4

Test Vehicle

Make Chevy
Model NOVA 2-Door Sedan
Year 1975
Transmission AUTOMATIC
A/C NO PB NO PS NO
License No. EPA-509

Engine Type V-8
Displacement 350
Nominal C.R. 9:1
Carb. Make Rochester No. Bbls. 4
Emission Control System STOCK
Odometer: Start Finish

Weather

Ambient Temp.: Start 78 °F
Finish °F

Observed Barom.: Start 29.91 in. Hg
Finish in. Hg

Relative Humidity: Start %
Finish %

CLAYTON #2

Road Conditions: Wet
Dry

Time: Start
Finish

Soak Time (hrs.)
Soak Temp. (°F)

Test Crew

Driver R. Hoerner
Recorder R. Flynn/R. Krupa

Observers

Remarks

Reproduced from best available copy.

Test No. ________
License *EPA-509*

Sheet 2 of 4

Cold Start-Driveaway

Start Miles	Mode		Idle					Accel. or Cruise					Backfire*
			Engine Speed rpm	Intake Vacuum in. Hg	Satis.	Rough*	Stall	Satis.	Hesit.*	Stumble*	Surge*	Stall	
	Start Time (sec.)	1											
	Restart (sec.)												
	Restart (sec.)												
	Restart (sec.)												
	Fast-Idle Cam		2100	21.5	✓								
	Tap Th. (5 sec. from St.)N		1700	21	✓								
	(10 sec. from Start)Dr		850	11	✓								
0	PT (0-25): Lt. Th. 12"							✓					
0.1	Cruise (25 mph) 30 seconds							✓					
0.2	PT (25-35): Th. to Detent 4"							✓					
0.3	WOT Accel. (0-35) 4"							✓					
0.4	PT (10-25): Lt. Th. 12"							✓					
0.5	Idle (30 sec.): Dr		670	18	✓								
	PT (0-25): Lt. Th.							✓					
0.6	Cruise (25 mph)							✓					
0.7	PT (25-35): Th. to Detent							✓					
0.8	WOT Accel. (0-35)							✓					
0.9	PT (10-25): Lt. Th.							✓					
1.0	Idle (30 sec.): Dr		670	18	✓								
	PT (0-25): Lt. Th.							✓					
1.1	Cruise (25 mph)							✓					
1.2	PT (25-35): Th. to Detent							✓					
1.3	WOT Accel. (0-35)							✓					
1.4	PT (10-25): Lt. Th.							✓					
1.5	Idle (30 sec.): Dr		660	18	✓								
	PT (0-45): Const. Vac. 12"							✓					
1.9	PT (25-35): Th. to Detent		change					✓					
2.0	WOT Accel. (0-35)							✓					
2.1	PT (10-25): Lt. Th.							✓					
2.2	Idle (30 sec.): Dr		660	18	✓								
	PT (0-45): Const. Vac.							✓					
2.6	PT (25-35): Th. to Detent							✓					
2.7	WOT Accel. (0-35)							✓					
2.8	PT (10-25): Lt. Th.							✓					
2.9	Idle (30 sec.): Dr		660	18	✓								

Test no. ________
License EPA-509

Cold Start-Driveaway

Start Miles	Mode	Idle					Acceleration					Backfire*
		Engine Speed rpm	Intake Vacuum In. Hg	Satis.	Rough*	Stall	Satis.	Hesit.*	Stumble*	Surge*	Stall	
	PT (0-45): Const. Vac.						✓					
3.3	PT (25-35): Th. to Detent						✓					
3.4	WOT Accel. (0-35)						✓					
3.5	PT (10-25): Lt. Th.						✓					
3.6	Idle (30 sec.): Dr	655	18	✓								
	PT (0-45): Const. Vac.						✓					
4.0	PT (25-35): Th. to Detent						✓					
4.1	WOT Accel. (0-35)						✓					
4.2	PT (10-25): Lt. Th.						✓					
4.3	Idle (30 sec.): Dr	650	18	✓								
	PT (0-45): Const. Vac.						✓					
4.7	PT (25-35): Th. to Detent						✓					
4.8	WOT Accel. (0-35)						✓					
4.9	PT (10-25): Lt. Th.						✓					
5.0	Idle (30 sec.): Dr	645	18	✓								
	PT (0-45): Const. Vac.						✓					
5.4	PT (25-35): Th. to Detent						✓					
5.5	WOT Accel. (0-35)						✓					
5.6	PT (10-25): Lt. Th.						✓					
5.7	Idle (30 sec.): Dr	650	18	✓								
	PT (0-45): Const. Vac.						✓					
6.1	PT (25-35): Th. to Detent						✓					
6.2	WOT Accel. (0-35)						✓					
6.3	PT (10-25): Lt. Th.						✓					
6.4	Idle (30 sec.): Dr	655	18	✓								

* T - Trace; M - Moderate; H - Heavy

Comments: ________________________________

Test No. ____
License EPA-509

Sheet 4 of 4

Warm Vehicle Evaluation

Mode		Accel. or Tip-In Satis.	Hesit.*	Stumble*	Surge*	Stall	Road Load Satis.	Stretchy	Surge*	X Idle Engine rpm	Vacuum in. Hg	Satis.	Rough*	Stall	Backfire*
Idle	N									890	20.5	✓			
	Dr									640	18	✓			
WOT Against 4" T.C.		✓													
Road Load	20 mph						✓								
	30 mph						✓								
	40 mph						✓								
	50 mph						✓								
	60 mph						✓								
	~~70 mph~~														
Retard → WOT Accel. (0-30)	Sudden	✓													
	Moderate	✓													
	Slow	✓													
PT Accel. (0-30)	1/4 Th.	✓													
	1/2 Th.	✓													
	3/4 Th.	✓													
PT Crowd (Min.-70 or Max.)	14 in.Hg	✓													
	12 in.Hg	✓													
	10 in.Hg	✓													
	8 in.Hg	✓													
	6 in.Hg	✓													
PT Tip-In (Top Gear)	From 20	✓													
	From 30	✓													

0-~~70~~ 60 mph 4" WOT Acceleration (sec.) 21

Drive 5 miles at 70 mph; Idle 30 sec.; Soak 15 min.
After soak, start according to manufacturer's hot-start procedure; Return to Idle

			Engine rpm	Vacuum in. Hg	Satis.	Rough*	Stall	Backfire*
Start Time (sec.)	1	Idle in Neutral (60 sec.)	790	19.5	✓			
Restart (sec.)								
Restart (sec.)								
Restart (sec.)								

Comments: ____

6° BTC

Date 12-16-77
Test Number
Fuel D-3

Proposed CRC
Driveability Test
Sheet 1 of 4

Test Vehicle

Make CHEVY
Model NOVA 2DR. SEDAN
Year 1975
Transmission AUTOMATIC
A/C NO PB PS
License No. EPA 509

Engine Type V-8
Displacement 350 CU. IN.
Nominal C.R. 9:1
Carb. Make ROCHESTER No. Bbls. 4
Emission Control System STOCK- KNOCK SENSOR CONTROL
Odometer: Start 40978.7 Finish 40999.3

Weather

Ambient Temp.: Start 78 °F
Finish 82 °F
Observed Barom.: Start 29.99 in. Hg
Finish in. Hg
Relative Humidity: Start %
Finish %

CLAYTON #2
Road Conditions: Wet
Dry
Time: Start
Finish
Soak Time (hrs.)
Soak Temp. (°F)

Test Crew

Driver R. HOERRNER
Recorder R. KRUPA

Observers

Remarks

Test No. ____________
License ____________

Sheet 2 of 4

Cold Start-Driveaway

			Idle					Accel. or Cruise					
Start Miles	Mode		Engine Speed rpm	Intake Vacuum in. Hg	Satis.	Rough*	Stall	Satis.	Hesit.*	Stumble*	Surge*	Stall	Backfire*
	Start Time (sec.)	1											
	Restart (sec.)												
	Restart (sec.)												
	Restart (sec.)												
	Fast-Idle Cam		2100	21.5	✓								
	Tap Th. (5 sec. from St.)N		1700	21	✓								
	(10 sec. from Start)Dr		590	17	✓								
0	PT (0-25): Lt. Th.							✓					
0.1	Cruise (25 mph)							✓					
0.2	PT (25-35): Th. to Detent							✓					
0.3	WOT Accel. (0-35)							✓					
0.4	PT (10-25): Lt. Th.							✓					
0.5	Idle (30 sec.): Dr		640	18	✓								
	PT (0-25): Lt. Th.							✓					
0.6	Cruise (25 mph)							✓					
0.7	PT (25-35): Th. to Detent							✓					
0.8	WOT Accel. (0-35)							✓					
0.9	PT (10-25): Lt. Th.							✓					
1.0	Idle (30 sec.): Dr		645	18	✓								
	PT (0-25): Lt. Th.							✓					
1.1	Cruise (25 mph)							✓					
1.2	PT (25-35): Th. to Detent							✓					
1.3	WOT Accel. (0-35)							✓					
1.4	PT (10-25): Lt. Th.							✓					
1.5	Idle (30 sec.): Dr		650	18	✓								
	PT (0-45): Const. Vac.							✓					
1.9	PT (25-35): Th. to Detent							✓					
2.0	WOT Accel. (0-35)							✓					
2.1	PT (10-25): Lt. Th.							✓					
2.2	Idle (30 sec.): Dr		650	18	✓								
	PT (0-45): Const. Vac.							✓					
2.6	PT (25-35): Th. to Detent							✓					
2.7	WOT Accel. (0-35)							✓					
2.8	PT (10-25): Lt. Th.							✓					
2.9	Idle (30 sec.): Dr		650	18	✓								

[illegible] No. ________________
License ________________

Cold Start-Driveaway

Start Miles	Mode	Idle: Engine Speed rpm	Idle: Intake Vacuum In. Hg	Idle: Satis.	Idle: Rough*	Idle: Stall	Acceleration: Satis.	Acceleration: Hesit.*	Acceleration: Stumble*	Acceleration: Surge*	Acceleration: Stall	Backfire*
	PT (0-45): Const. Vac.						✓					
3.3	PT (25-35): Th. to Detent						✓					
3.4	WOT Accel. (0-35)						✓					
3.5	PT (10-25): Lt. Th.						✓					
3.6	Idle (30 sec.): Dr	660	18	✓								
	PT (0-45): Const. Vac.						✓					
4.0	PT (25-35): Th. to Detent						✓					
4.1	WOT Accel. (0-35)						✓					
4.2	PT (10-25): Lt. Th.						✓					
4.3	Idle (30 sec.): Dr	655	17	✓								
	PT (0-45): Const. Vac.						✓					
4.7	PT (25-35): Th. to Detent						✓					
4.8	WOT Accel. (0-35)						✓					
4.9	PT (10-25): Lt. Th.						✓					
5.0	Idle (30 sec.): Dr	660	18	✓								
	PT (0-45): Const. Vac.						✓					
5.4	PT (25-35): Th. to Detent						✓					
5.5	WOT Accel. (0-35)						✓					
5.6	PT (10-25): Lt. Th.						✓					
5.7	Idle (30 sec.): Dr	660	18	✓								
	PT (0-45): Const. Vac.						✓					
6.1	PT (25-35): Th. to Detent						✓					
6.2	WOT Accel. (0-35)						✓					
6.3	PT (10-25): Lt. Th.						✓					
6.4	Idle (30 sec.): Dr	660	18	✓								

* T - Trace; M - Moderate; H - Heavy

Comments: 1 STALL ON DROPPING INTO DRIVE - RE START O.K.

Test No. ______________
License ______________

Warm Vehicle Evaluation

Mode		Accel. or Tip-In					Road Load			Idle					Backfire*
		Satis.	Hesit.*	Stumble*	Surge*	Stall	Satis.	Stretchy	Surge*	Engine rpm	Vacuum in. Hg	Satis.	Rough*	Stall	
Idle	N									890	20	✓			
	Dr									665	18	✓			
WOT Against T.C.		✓													
Road Load	20 mph						✓								
	30 mph						✓								
	40 mph						✓								
	50 mph						✓								
	60 mph						✓								
	~~70~~ mph														
WOT Accel. (0-30)	Sudden	✓													
	Moderate	✓													
	Slow	✓													
PT Accel. (0-30)	1/4 Th.	✓													
	1/2 Th.	✓													
	3/4 Th.	✓													
PT Crowd (Min.-70 or Max.)	14 in.Hg	✓													
	12 in.Hg	✓													
	10 in.Hg	✓													
	8 in.Hg	✓													
	6 in.Hg	✓													
PT Tip-In (Top Gear)	From 20	✓													
	From 30	✓													

0-~~70~~ 60 mph WOT Acceleration (sec.) 15

Drive 5 miles at ~~70~~ 60 mph; Idle 30 sec.; Soak 15 min.
After soak, start according to manufacturer's hot-start procedure; Return to Idle

Start Time (sec.)	2	Idle in Neutral (60 sec.)	660	17				
Restart (sec.)								
Restart (sec.)								
Restart (sec.)								

Comments: ____
____
____

Date 12/20/77
Test Number ______
Fuel D-4

Proposed CRC
Driveability Test
Sheet 1 of 4

Test Vehicle

Make CHEVY
Model NOVA
Year 1975
Transmission Auto
A/C NO PB NO PS yes
License No. EPA-509

Engine Type V-8
Displacement 350
Nominal C.R. 9:1
Carb. Make Rochester No. Bbls. 4
Emission Control System G.M. EGR Valve
Odometer: Start 21028.5 Finish ______

Weather

Ambient Temp.: Start ______ °F
Finish ______ °F
Observed Barom.: Start ______ in. Hg
Finish ______ in. Hg
Relative Humidity: Start ______ %
Finish ______ %

Clayton #2
~~Road Conditions~~: Wet ______
Dry ______
Time: Start ______
Finish ______
Soak Time (hrs.) ______
Soak Temp. (°F) ______

Test Crew

Driver R. Hoekner
Recorder L. HURST
Observers ______

Remarks

Test No. D-4
License EPA-509

Cold Start-Driveaway

Start Miles	Mode		Idle					Accel. or Cruise					Backfire*
			Engine Speed rpm	Intake Vacuum in. Hg	Satis.	Rough*	Stall	Satis.	Hesit.*	Stumble*	Surge*	Stall	
	Start Time (sec.)	1											
	Restart (sec.)												
	Restart (sec.)												
	Restart (sec.)												
	Fast-Idle Cam		2100	21.0	✓								
	Tap Th. (5 sec. from St.)N		760	19.5		T							
	(10 sec. from Start)Dr		610	16.5		T							
0	PT (0-25): Lt. Th. 12°							✓					
0.1	Cruise (25 mph)							✓					
0.2	PT (25-35): Th. to Detent 4°							✓					
0.3	WOT Accel. (0-35) 4							✓					
0.4	PT (10-25): Lt. Th.										T		
0.5	Idle (30 sec.): Dr		680	17.5	✓								
	PT (0-25): Lt. Th.								T				
0.6	Cruise (25 mph)							✓					
0.7	PT (25-35): Th. to Detent							✓					
0.8	WOT Accel. (0-35)							✓					
0.9	PT (10-25): Lt. Th.										T		
1.0	Idle (30 sec.): Dr		650	17.5	✓								
	PT (0-25): Lt. Th.							✓					
1.1	Cruise (25 mph)							✓					
1.2	PT (25-35): Th. to Detent							✓					
1.3	WOT Accel. (0-35)							✓					
1.4	PT (10-25): Lt. Th.							✓					
1.5	Idle (30 sec.): Dr		650	17.5	✓								
	PT (0-45): Const. Vac.							✓					
1.9	PT (25-35): Th. to Detent							✓					
2.0	WOT Accel. (0-35)							✓					
2.1	PT (10-25): Lt. Th.							✓					
2.2	Idle (30 sec.): Dr		640	17.0	✓								
	PT (0-45): Const. Vac.							✓					
2.6	PT (25-35): Th. to Detent							✓					
2.7	WOT Accel. (0-35)							✓					
2.8	PT (10-25): Lt. Th.							✓					
2.9	Idle (30 sec.): Dr		650	17.5	✓								

[illegible] No. ________

License EPA-509

D-4

Cold Start-Driveaway

Start Miles	Mode	Idle					Acceleration					Backfire*
		Engine Speed rpm	Intake Vacuum In. Hg	Satis.	Rough*	Stall	Satis.	Hesit.*	Stumble*	Surge*	Stall	
	PT (0-45): Const. Vac.						✓					
3.3	PT (25-35): Th. to Detent						✓					
3.4	WOT Accel. (0-35)						✓					
3.5	PT (10-25): Lt. Th.						✓					
3.6	Idle (30 sec.): Dr	650	17.5	✓								
	PT (0-45): Const. Vac.						✓					
4.0	PT (25-35): Th. to Detent						✓					
4.1	WOT Accel. (0-35)						✓					
4.2	PT (10-25): Lt. Th.						✓					
4.3	Idle (30 sec.): Dr	640	17.0	✓								
	PT (0-45): Const. Vac.						✓					
4.7	PT (25-35): Th. to Detent						✓					
4.8	WOT Accel. (0-35)						✓					
4.9	PT (10-25): Lt. Th.						✓					
5.0	Idle (30 sec.): Dr	660	18.0	✓								
	PT (0-45): Const. Vac.						✓					
5.4	PT (25-35): Th. to Detent						✓					
5.5	WOT Accel. (0-35)						✓					
5.6	PT (10-25): Lt. Th.						✓					
5.7	Idle (30 sec.): Dr	650	18.0	✓								
	PT (0-45): Const. Vac.						✓					
6.1	PT (25-35): Th. to Detent						✓					
6.2	WOT Accel. (0-35)						✓					
6.3	PT (10-25): Lt. Th.						✓					
6.4	Idle (30 sec.): Dr	660	18.0									

* T - Trace; M - Moderate; H - Heavy

Comments: ____

Case No. ____________
License ____________

Warm Vehicle Evaluation

Mode		Accel. or Tip-In					Road Load			Idle					Backfire*
		Satis.	Hesit.*	Stumble*	Surge*	Stall	Satis.	Stretchy	Surge*	Engine rpm	Vacuum in. Hg	Satis.	Rough*	Stall	
Idle	N									900	20.5	✓			
	Dr									660	17.5	✓			
WOT Against T.C.		✓													
Road Load	20 mph						✓								
	30 mph						✓								
	40 mph						✓								
	50 mph						✓								
	60 mph						✓								
	~~70 mph~~														
WOT Accel. (0-30)	Sudden	✓													
	Moderate	✓													
	Slow	✓													
PT Accel. (0-30)	1/4 Th.	✓					12"								
	1/2 Th.	✓					9"								
	3/4 Th.	✓					6"								
PT Crowd (Min.-70 or Max.) 20 - 60	14 in.Hg	✓													
	12 in.Hg	✓													
	10 in.Hg	✓													
	8 in.Hg	✓													
	6 in.Hg	✓													
PT Tip-In (Top Gear)	From 20	✓													
	From 30	✓													

0-~~70~~60 mph @ 4" WOT Acceleration (sec.) 22.0

Drive 5 miles at 70 mph; Idle 30 sec.; Soak 15 min.
After soak, start according to manufacturer's hot-start procedure; Return to Idle

Start Time (sec.)	3	Idle in Neutral (60 sec.)	750	19.0		T		
Restart (sec.)								
Restart (sec.)								
Restart (sec.)								

Comments: ____
____
____

APPENDIX E

DUAL SPARK PLUG IGNITION TESTING

E-1 through E-8 Comparison of Single U.S. Dual Ignition

E-9 Method Used for Calculating EGR Flow

APPENDIX E-1

COMPARISON OF SINGLE AND DUAL IGNITION AT 10" MANIFOLD VACUUM

RPM	Spark Timing		Avg. Torque	Engine Out Emissions			Octane Req. (PRF)
	P	S		CO (%)	NO_x (ppm)	HC (ppm)	
1500	23	----	138	0.5	730	180	81
1500	23	23.5	149	0.5	1150	210	--
1500	16	16	138	0.5	620	170	83
1500	24	----	138	0.5	650	215	--
1500	24	24	148	0.5	1000	225	--
1500	16.5	16.5	138	0.5	550	175	--
1500	16.5	----	125	0.5	350	140	--
2000	29	----	150.5	0.9	1325	185	81
2000	29	29	153	1.0	1850	205	--
2000	23	23	150.5	1.0	1300	180	85
2000	29	--	148.5	1.0	970	165	--
2000	29	29	153.5	1.0	1350	190	--
2000	22	22	149	1.0	780	145	--

P - Primary plugs.
S - Secondary plugs.
Fuel: Isooctane

APPENDIX E-2

RPM	Spark Timing		Avg. Torque	Engine Out Emissions			Octane Req. (PRF)
	P	S		CO (%)	NO_x (ppm)	HC (ppm)	
2000	30.5	———	142	1.0	1050	180	--
2000	30.5	30.5	147	1.0	1425	200	--
2000	22	22	142	1.0	800	160	--
2000	22	———	131	1.0	550	125	--
2500	31.5	———	148.5	1.2	1425	135	80
2500	31.5	31.5	153.5	1.6	2000	145	--
2500	25.5	25.5	148.5	1.1	760	80	81
2500	33.5	———	144	1.6	975	145	--
2500	33.5	33.5	149	1.6	1500	160	--
2500	22.5	22.5	144	1.4	650	100	--
2500	22.5	———	133.5	1.3	500	80	--
3000	34.5	———	142.5	1.5	1150	75	81
3000	34.5	34.5	147	1.8	1700	110	--
3000	25.5	25.5	142.5	1.6	950	75	80
3000	36	———	132.5	1.5	875	85	--
3000	36	36	138	1.9	1250	110	--
3000	27	27	132.5	1.6	700	120	--
3000	27	———	124	1.4	525	55	--

APPENDIX E-3

COMPARISON OF SINGLE AND DUAL IGNITION AT 2000 RPM, VARIABLE LOAD

Manifold Vacuum (in. Hg)	Spark Timing P	Spark Timing S	Avg. Torque	Engine Out Emissions CO (%)	Engine Out Emissions NO_x (ppm)	Engine Out Emissions HC (ppm)	Octane Req. (PRF)
3	15.5	--	256	>5	710	325	98
3	16	16	260	>5	720	320	--
3	14	14	256	>5	700	320	>99
6	22.5	--	190	1.7	650	140	89
6	22	22	195	1.7	980	170	--
6	18	18	190	1.7	770	150	92
9	27	--	160	1.1	925	165	84
9	27	27	166.5	1.2	1200	175	--
9	22	22	160	1.2	900	145	86
12	34	--	122.5	0.7	1075	180	75
12	34	34	125	0.7	1550	170	--
12	26	26	123	0.7	1000	150	79

APPENDIX E-4

FUEL CONSUMPTION OF DUAL IGNITION ENGINE

RPM	Manifold Vacuum (in.)	Spark Timing (°BTC) P	Spark Timing (°BTC) S	Average Torque (ft-lb)	Fuel Consumption (lb/min)	% Reduction
1500	10.0	24.5	----	140	0.331	
1500	10.2	24.5	24.5	151.5	0.335	
1500	10.0	24.5		141.5	0.335	
1500	9.9	17	17	141	0.333	
1500	9.9	25	----	136	0.325	
1500	9.9	25	25	144.5	----- 0.310	4.6%
1500	10.4 Throttle Adj.	25	25	136		
1500	10.0	25	----	134.5	0.317	
1500	10.0	25	25	141	----- 0.307	3.2%
1500	10.6 Throttle Adj.	25	25	135		
2000	3.0	18	----	251	0.898	
2000	3.0	18	18	258	----- 0.870	3.1%
2000	3.5 Throttle Adj.	18	18	251		
2000	3.0	17.5	----	255	0.908	
2000	2.9	18	18	264	----- 0.866	4.6%
2000	3.4 Throttle Adj.	18	18	255		
2500	10.0	33	----	158.5	0.608	
2500	9.8	33	33	165	----- 0.598	1.6%
2500	10.1 Throttle Adj.	33	33	159		

APPENDIX E-5

EFFECT OF INCREASED EGR FLOW ON OCTANE REQUIREMENT, FUEL CONSUMPTION, AND EMISSIONS OF DUAL IGNITION ENGINE USING GM PROPORTION RECYCLE VALVE (CONSTANT THROTTLE EXCEPT WHERE NOTED)

	Description	Engine RPM	Manifold Vacuum	% EGR	Torque	Research Octane Requirement	CO(%)	HC(ppm)	NO_x(ppm)	Fuel Consumption (lb/min)
Test #1	a. Single Ignition - (Base)	1500	10.0	7.4	133	83	0.5	175	750	0.328
	b. Dual Ignition	1500	10.0	7.4	143	---	---	---	---	---
	c. Dual Ignition - Increased EGR	1500	9.3	13.5	133	86	0.5	220	550	0.326
	Comparison of Single → Dual (a→c) at Equal Torque					+3	0	+26%	-27%	-0.6%
Test #2	a. Single Ignition - (Base)	2000	10.0	5.7	134	80	0.95	200	900	0.442
	b. Dual Ignition	2000	10.1	5.7	141	---	---	---	---	---
	c. Dual Ignition - Increased EGR	2000	9.0	11.9	134	86	0.95	230	680	0.430
	Comparison of Single → Dual (a→c) at Equal Torque					+6	0	+15%	-24%	-2.7%

* Octane requirements determined at steady state with Primary Reference Fuels (P Series). Emissions and fuel economy determined with isooctane fuel.

APPENDIX E-6

EFFECT OF INCREASED EGR ON OCTANE REQUIREMENT, FUEL CONSUMPTION, AND EMISSIONS OF DUAL IGNITION ENGINE

	Description	Engine RPM	Manifold Vacuum	% EGR	Torque	Research Octane Requirement	CO(%)	HC(ppm)	NO_x(ppm)	Fuel Consumption (lb/min)
Test #5	A. Single Ignition - (Base)	2500	10.0	4.6	143	81	1.1	130	1300	0.584
	B. Dual Ignition	2500	10.0	4.6	145	---	---	---	---	---
	C. Dual Ignition - Increased EGR	2500	9.3	10.2	142	88	1.1	180	1250	0.558
	Comparison of Single → Dual (A→C) at Equal Torque					+7	0	+38%	-4%	-4.5%
Test #6	A. Single Ignition - (Base)	2000	6.0	4.7	170	88	1.3	125	760	0.554
	B. Dual Ignition	2000	5.9	4.7	181	---	1.3	165	750	---
	C. Dual Ignition - Increased EGR	2000	5.4	8.8	170	92	1.4	190	450	0.545
	Comparison of Single → Dual (A→C) at Equal Torque					+4	+8%	+52%	-41%	-1.6%

APPENDIX E-7

EFFECT OF INCREASED EGR ON OCTANE REQUIREMENT, FUEL CONSUMPTION, AND EMISSIONS OF DUAL IGNITION ENGINE

	Description	Engine RPM	Manifold Vacuum	% EGR	Torque	Research Octane Requirement	CO(%)	HC(ppm)	NO_x(ppm)	Fuel Consumption (lb/min)
[illegible]	A. Single Ignition – (Base)	2000	6.0	4.5	178	87	1.1	125	550	0.554
	B. Dual Ignition	2000	6.0	4.5	190	---	1.1	150	720	---
	C. Dual Ignition – Increased EGR	2000	5.6	7.5	180	92	1.3	160	560	0.544
	Comparison of Single → Dual (A→C) at Equal Torque					+5	+18%	+28%	+2%	-1.8%
	D. Dual Ignition – More EGR – Throttle Adjusted to Equalize Torque	2000	4.5	12.6	179	87	2.3	155	300	0.568
	Comparison of Single → Dual (A→D) at Equal Torque					0	+109%	+24%	-45%	+2.5%
[illegible]	A. Single Ignition – (Base)	2000	3.0	<0.5	246	91	>5	325	NO_x Instrument Malfunction	0.889
	B. Dual Ignition	2000	3.0	<0.5	254	---	>5	325		---
	C. Dual Ignition – Increased EGR	2000	2.7	6.1	246	99	>5	330		0.842
	Comparison of Single → Dual (A→C) at Equal Torque					+8		+2%		-5.3%
	D. Dual Ignition – More EGR – Throttle Adjusted to Equalize Torque	2000	1.6	8.1	240	>100	>5	350		0.834
	Comparison of Single → Dual (A→D) at Equal Torque					>+9		+7.7%		-6.2%

APPENDIX E-8

EFFECT OF INCREASED EGR ON OCTANE REQUIREMENT, FUEL CONSUMPTION, AND EMISSIONS OF DUAL IGNITION ENGINE

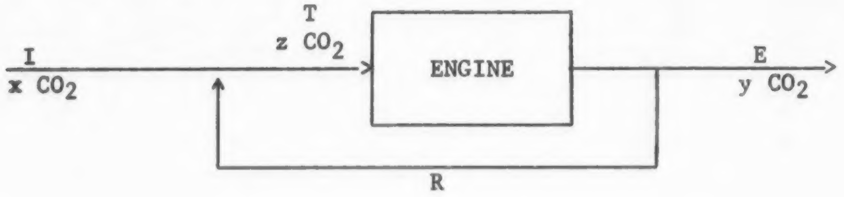
Test #7

Description	Engine RPM	Manifold Vacuum	% EGR	Torque	Research Octane Requirement	CO(%)	HC(ppm)	NO_x(ppm)	Fuel Consumption (lb/min)
A. Single Ignition - (Base)	2000	10.0	5.6	149	82	0.25	155	1800	0.446
B. Dual Ignition	2000	9.8	5.6	155	---	0.25	180	2500	---
C. Dual Ignition - Increased EGR	2000	9.0	13.0	149	90	0.25	175	1325	0.428
Comparison of Single - Dual (A-C) at Equal Torque					+8	0	+13%	-26%	-4.0%
D. Dual Ignition - More EGR - Throttle Adjusted to Equalize Torque	2000	7.8	16.1	149	86	0.25	160	850	0.437
Comparison of Single - Dual (A-D) at Equal Torque					+4	0	+3%	-53%	-2.0%

APPENDIX E-9

METHOD FOR CALCULATING PERCENTAGE EGR FLOW

EGR flow can be calculated from measurement of CO_2 concentrations in the exhaust and intake manifolds. The calculation procedure is outlined below.



The total flow into the engine consists of

(1) $I + R = T$. The CO_2 balance equation is

(2) $xI + yR = zT$

where x, y, and z are the fractional CO_2 concentrations in the intake air, exhaust manifold, and in the intake manifold respectively. Substitution of equation (1) into (2) gives

(3) $$\frac{R}{I} = \frac{z - x}{y - z}$$

Measurements of x, the CO_2 concentration in the intake air show it to be negligible. The basic combustion equation is given by

(4) $$CH_n + 3.76\ R\ N_2 + RO_2 + (7.63\ hR)\ H_2O \longrightarrow$$
$$CO_2 + (\frac{n}{2} + 7.63\ hR)\ H_2O + 3.76\ R\ N_2 + (R - \frac{n}{4} - 1)O_2$$

where n is the hydrogen/carbon ratio of the fuel, R is a measure of the intake air flow, and h is the humidity in lb H_2O/lb dry air. Since the CO_2 measurement procedure traps the H_2O prior to measurement, the CO_2 concentration is on a dry basis and needs to be converted to a wet basis. From equation 3 the concentration of CO_2 (dry) in the exhaust is given by

(5) $$y_{(dry)} = \frac{1}{1 + 3.76\ R + (R - \frac{n}{4} - 1)}$$

Thus R can be estimated from the CO_2 concentration in the exhaust by rearrangement of equation 5.

$$(6) \quad R = \frac{1}{4.76} \left(\frac{1}{y} + \frac{n}{4}\right)$$

The CO_2 concentration on a wet basis is given by

$$(7) \quad y' \equiv y\ (\text{wet}) = \frac{1}{1 + 3.76\ R + (R - \frac{n}{4} - 1) + (\frac{n}{2} + 7.63\ hR)}$$

y' can be expressed in terms of y using

$$(8) \quad y' = \left(\frac{4.76\ R - \frac{n}{4}}{\frac{n}{4} + 7.63\ hR + 4.76\ R}\right) y$$

In general the H_2O content of the intake manifold mixture is so low that no correction is necessary for Z, the intake manifold CO_2 concentration. However, for high levels of recycle some correction may be necessary and is given by

$$(9) \quad z' \equiv z_{(\text{wet})} = z \left(\frac{1}{1 + \frac{29}{18}\ h + [H_2O]_{EXH}\ \frac{[CO_2]_{IM}}{[CO_2]_{EXH}}}\right)$$

$$z' = z \left[\frac{1}{1 + \frac{29}{18}\ h + (1 - \frac{y'}{y})\ (\frac{z}{y'})}\right]$$

With the H_2O converted CO_2 concentrations calculated (z' and y'), equation 3 can be directly applied (ignoring the z term) to calculate R/I the fractional recycle flow.

APPENDIX F

FREQUENCY ANALYSIS OF ALTERNATE ENGINE

F-1 2.3 Liter Pinto L-4 Engine

F-2 2.8 Liter Ford V-6 Engine

APPENDIX F-1

Frequency Analysis Of 2.3 Liter, 4 Cylinder Pinto Engine

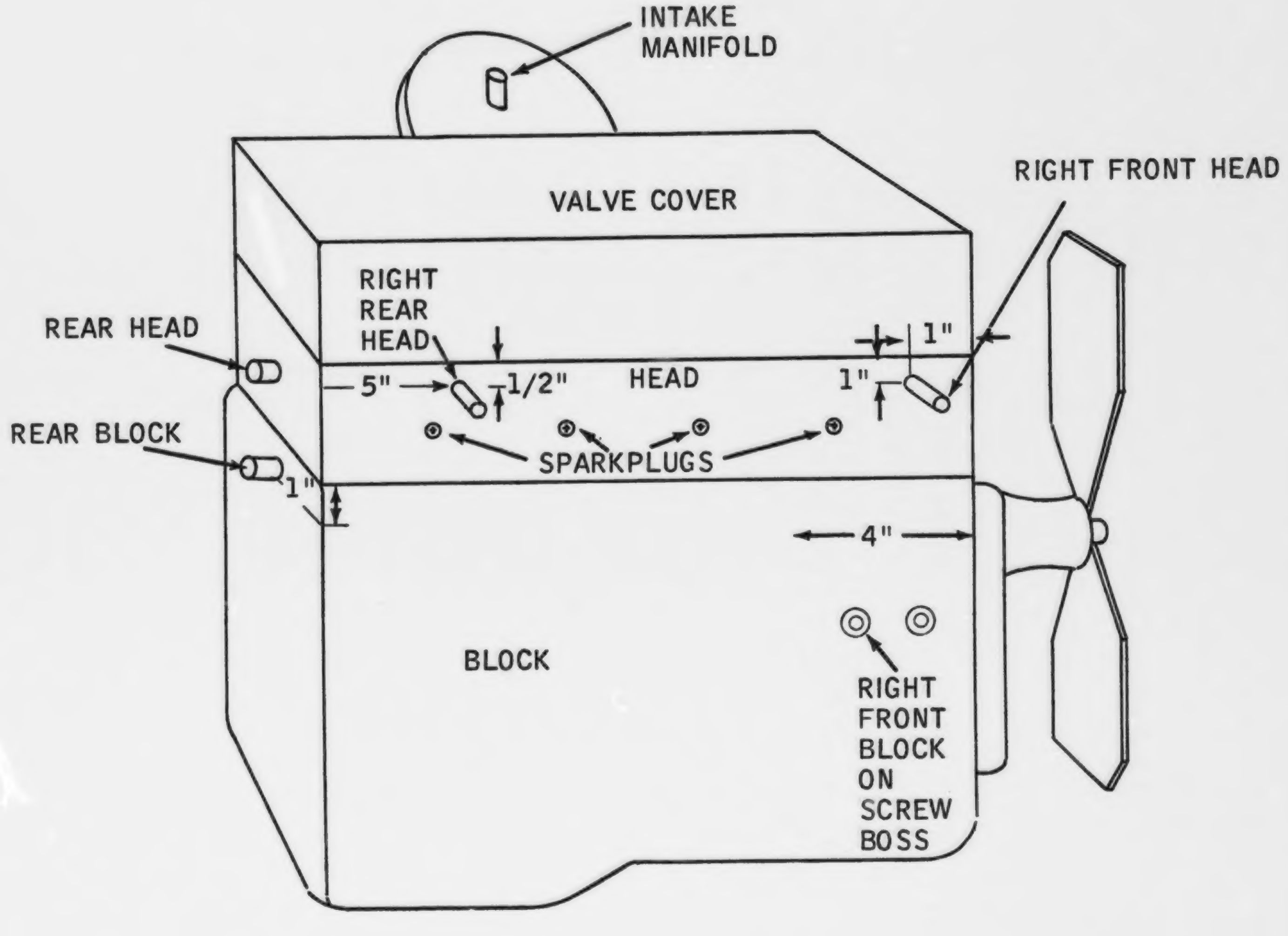
Run No.	Accelerometer	Speed	Knock Rating
P 1 - 5	Rear head	2600 RPM Fuel Change	VL to NK
P 1 - 6	Rear block	2600 RPM Fuel Change	VL to NK
P 1 - 7	Right front head	2600 RPM Fuel Change	VL to NK
P 2 - 5	Rear head	2600 RPM Fuel Change	NK to VL
P 2 - 6	Rear block	2600 RPM Fuel Change	NK to VL
P 2 - 7	Right front head	2600 RPM Fuel Change	NK to VL
P 3 - 5	Intake Manifold	2600 RPM Fuel Change	NK to VL
P 3 - 6	Right rear head	2600 RPM Fuel Change	NK to VL
P 3 - 7	Right front block	2600 RPM Fuel Change	NK to VL
P 4 - 5	Intake Manifold	1600 RPM Fuel Change	VL to NK
P 4 - 6	Right rear head	1600 RPM Fuel Change	VL to NK
P 4 - 7	Right front block	1600 RPM Fuel Change	VL to NK
P 5 - 5	Intake Manifold	2600 RPM Fuel Change	NK to VL
P 5 - 6	Right rear head	2600 RPM Fuel Change	NK to VL
P 5 - 7	Right front block	2600 RPM Fuel Change	NK to VL
P 6 - 5	Intake Manifold	1600 RPM Fuel Change	NK to VL
P 6 - 6	Right rear head	1600 RPM Fuel Change	NK to VL
P 6 - 7	Right front block	1600 RPM Fuel Change	NK to VL

Run No.	Accelerometer	Speed	Knock Rating
P 10 - 5	Rear head	30 to 60 MPH Accel.	NK
P 10 - 6	Rear block	30 to 60 MPH Accel.	NK
P 10 - 7	Right front head	30 to 60 MPH Accel.	NK
P 11 - 5	Intake Manifold	30 to 60 MPH Accel.	NK
P 11 - 6	Right rear head	30 to 60 MPH Accel.	NK
P 11 - 7	Right front block	30 to 60 MPH Accel.	NK
P 12 - 5	Intake Manifold	30 to 60 MPH Accel.	VL
P 12 - 6	Right rear head	30 to 60 MPH Accel.	VL
P 12 - 7	Right front block	30 to 60 MPH Accel.	VL
P 13 - 5	Rear head	30 to 60 MPH Accel.	L
P 13 - 6	Rear block	30 to 60 MPH Accel.	L
P 13 - 7	Right front head	30 to 60 MPH Accel.	L
P 14 - 5	Rear head	30 to 60 MPH Accel.	NK
P 14 - 6	Rear block	30 to 60 MPH Accel.	NK
P 15 - 5	Intake Manifold	30 to 60 MPH Accel.	NK
P 15 - 6	Right rear head	30 to 60 MPH Accel.	NK
P 15 - 7	Right front block	30 to 60 MPH Accel.	NK
P 16 - 5	Intake Manifold	30 to 60 MPH Accel.	T-
P 16 - 6	Right rear head	30 to 60 MPH Accel.	T-
P 16 - 7	Right front block	30 to 60 MPH Accel.	T-

Run No.	Accelerometer	Speed	Knock Rating
P 17 - 5	Rear head	30 to 60 MPH Accel.	T-
P 17 - 6	Rear block	30 to 60 MPH Accel.	T-
P 17 - 7	Right front head	30 to 60 MPH Accel.	T-
P 18 - 5	Rear head	30 to 60 MPH Accel.	T /T+
P 18 - 6	Rear block	30 to 60 MPH Accel.	T /T+
P 18 - 7	Right front head	30 to 60 MPH Accel.	T /T+
P 19 - 5	Intake Manifold	30 to 60 MPH Accel.	T /T+
P 19 - 6	Right rear head	30 to 60 MPH Accel.	T /T+
P 19 - 7	Right front head	30 to 60 MPH Accel.	T /T+
P 20 - 5	Rear head	1600 RPM	T+
P 20 - 6	Rear block	1600 RPM	T+
P 20 - 7	Right front head	1600 RPM	T+
P 21 - 5	Intake Manifold	1600 RPM	T+
P 21 - 6	Right rear head	1600 RPM	T+
P 21 - 7	Right front block	1600 RPM	T+
P 22 - 5	Intake manifold	1600 RPM	T-
P 22 - 6	Right rear head	1600 RPM	T-
P 22 - 7	Right front block	1600 RPM	T-
P 23 - 5	Rear head	1600 RPM	T-
P 23 - 6	Rear block	1600 RPM	T-
P 23 - 7	Right front head	1600 RPM	T-
P 24 - 5	Rear head	2600 RPM	T+
P 24 - 6	Rear block	2600 RPM	T+
P 24 - 7	Right front head	2600 RPM	T+
P 25 - 5	Intake Manifold	2600 RPM	T+
P 25 - 6	Right rear head	2600 RPM	T+
P 25 - 7	Right front block	2600 RPM	T+
P 26 - 5	Intake Manifold	2600 RPM	T-
P 26 - 6	Right rear head	2600 RPM	T-
P 26 - 7	Right front block	2600 RPM	T-

Run No.	Accelerometer	Speed	Knock Rating
P 27 - 5	Rear head	2600 RPM	T-
P 27 - 6	Rear block	2600 RPM	T-
P 27 - 7	Right front head	2600 RPM	T-
P 28 - 5	Rear head	2600 RPM	NK
P 28 - 6	Rear block	2600 RPM	NK
P 28 - 7	Right front head	2600 RPM	NK
P 29 - 5	Intake Manifold	2600 RPM	NK
P 29 - 6	Right rear head	2600 RPM	NK
P 29 - 7	Right front block	2600 RPM	NK
P 30 - 5	Intake Manifold	2600 RPM	NK
P 30 - 6	Right rear head	2600 RPM	NK
P 30 - 7	Right front block	2600 RPM	NK
P 31 - 5	Rear head	2600 RPM	NK
P 31 - 6	Rear block	2600 RPM	NK
P 31 - 7	Right front head	2600 RPM	NK
P 32 - 5	Rear head	1600 RPM	NK
P 32 - 6	Rear block	1600 RPM	NK
P 32 - 7	Right front head	1600 RPM	NK
P 33 - 5	Intake manifold	1600 RPM	NK
P 33 - 6	Right rear head	1600 RPM	NK
P 33 - 7	Right front block	1600 RPM	NK
P 34 - 5	Intake manifold	1600 RPM	NK
P 34 - 6	Right rear head	1600 RPM	NK
P 34 - 7	Right front block	1600 RPM	NK
P 35 - 5	Rear head	1600 RPM	NK
P 35 - 6	Rear block	1600 RPM	NK
P 35 - 7	Right front head	1600 RPM	NK

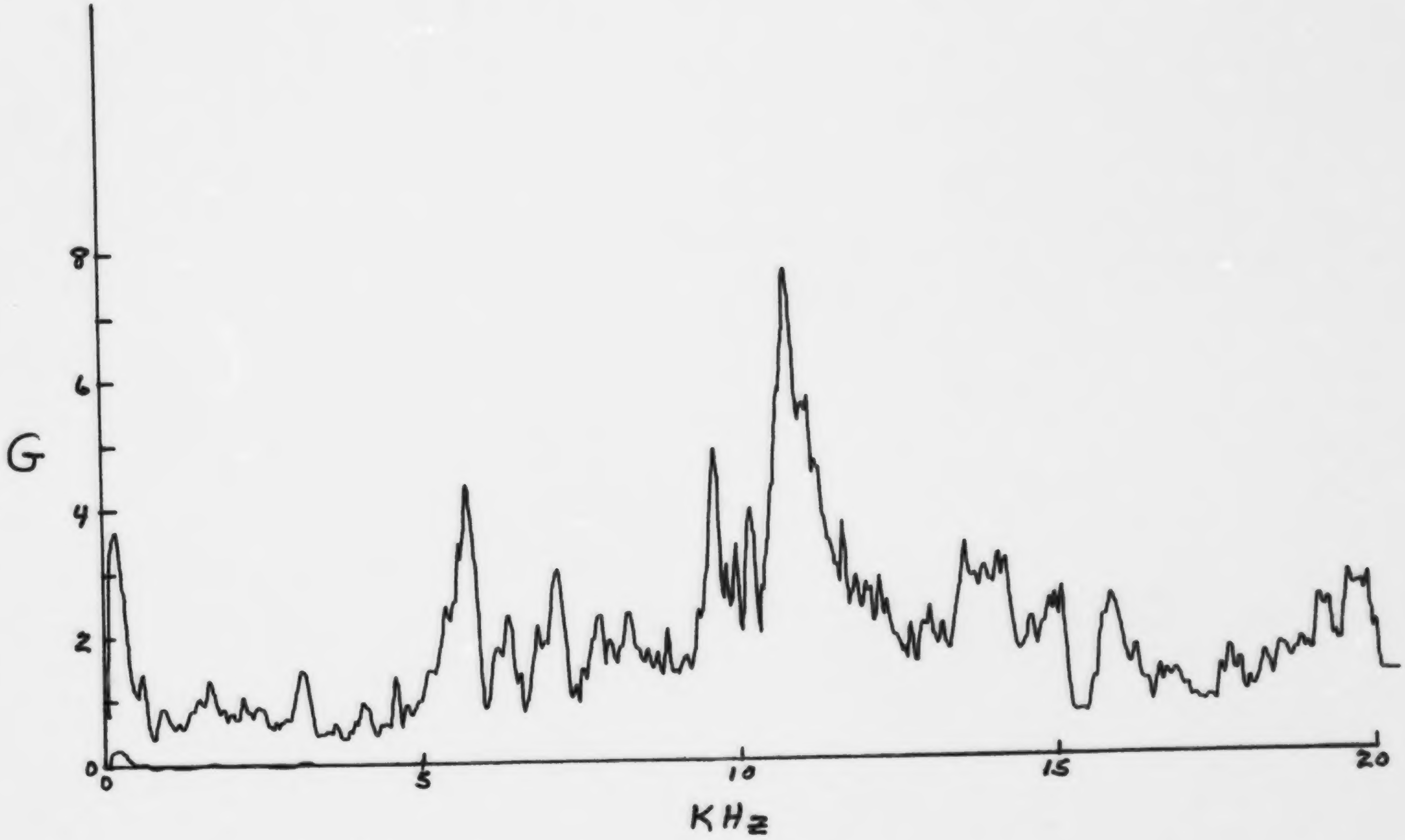
LOCATION OF ACCELEROMETERS ON
2.3 LITER 4 CYLINDER PINTO ENGINE (SIDE VIEW)


INTAKE MANIFOLD
VALVE COVER
RIGHT FRONT HEAD
RIGHT REAR HEAD
REAR HEAD
REAR BLOCK
HEAD
1"
1"
5"
1/2"
1"
SPARKPLUGS
4"
BLOCK
RIGHT FRONT BLOCK ON SCREW BOSS

P1-5

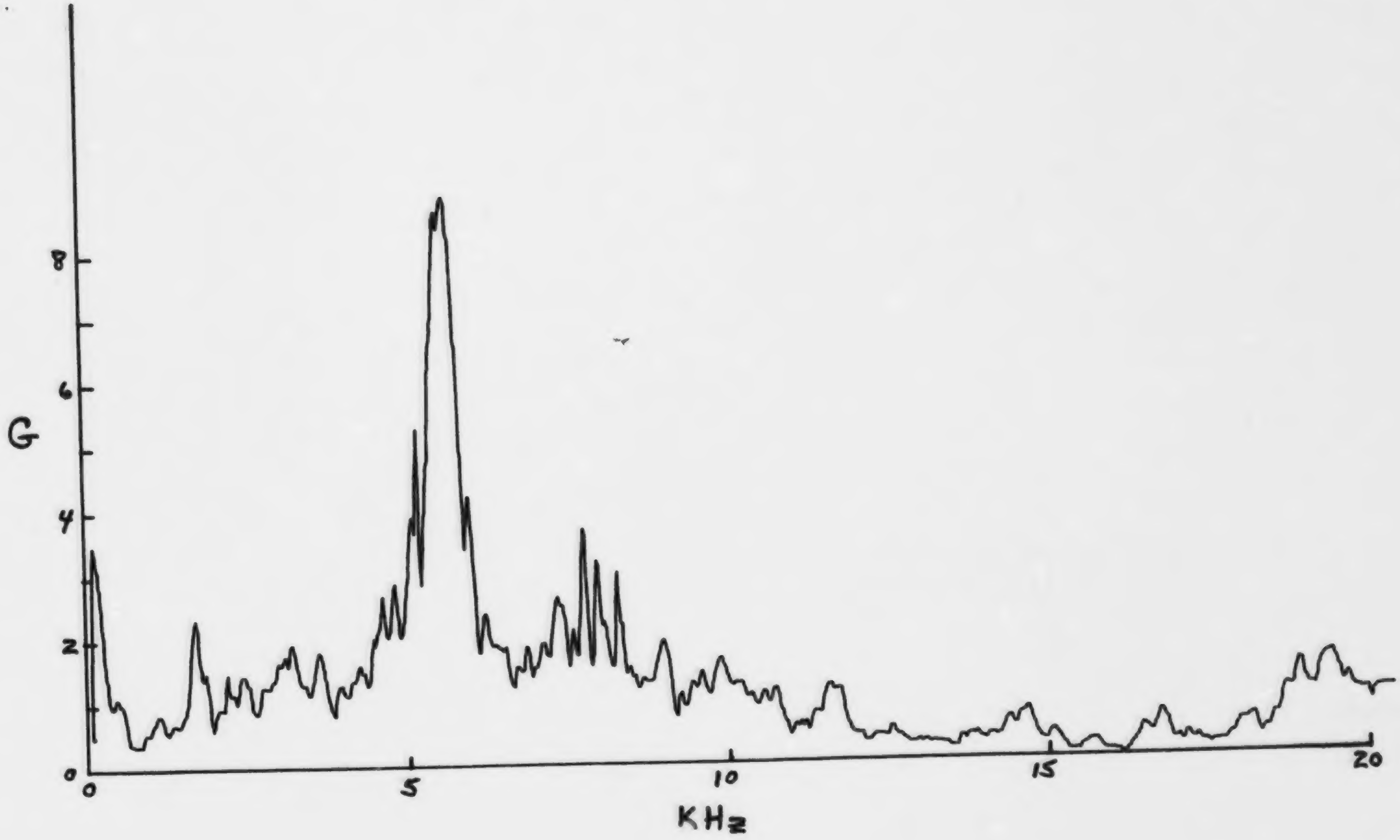
160-190
record 3.16IN
20DB
plot 0DB

P1 - 5   2.3 L, 4 cyl.
Rear Head, C90, 2600 RPM
VL Knock to NK (TI 160/190)



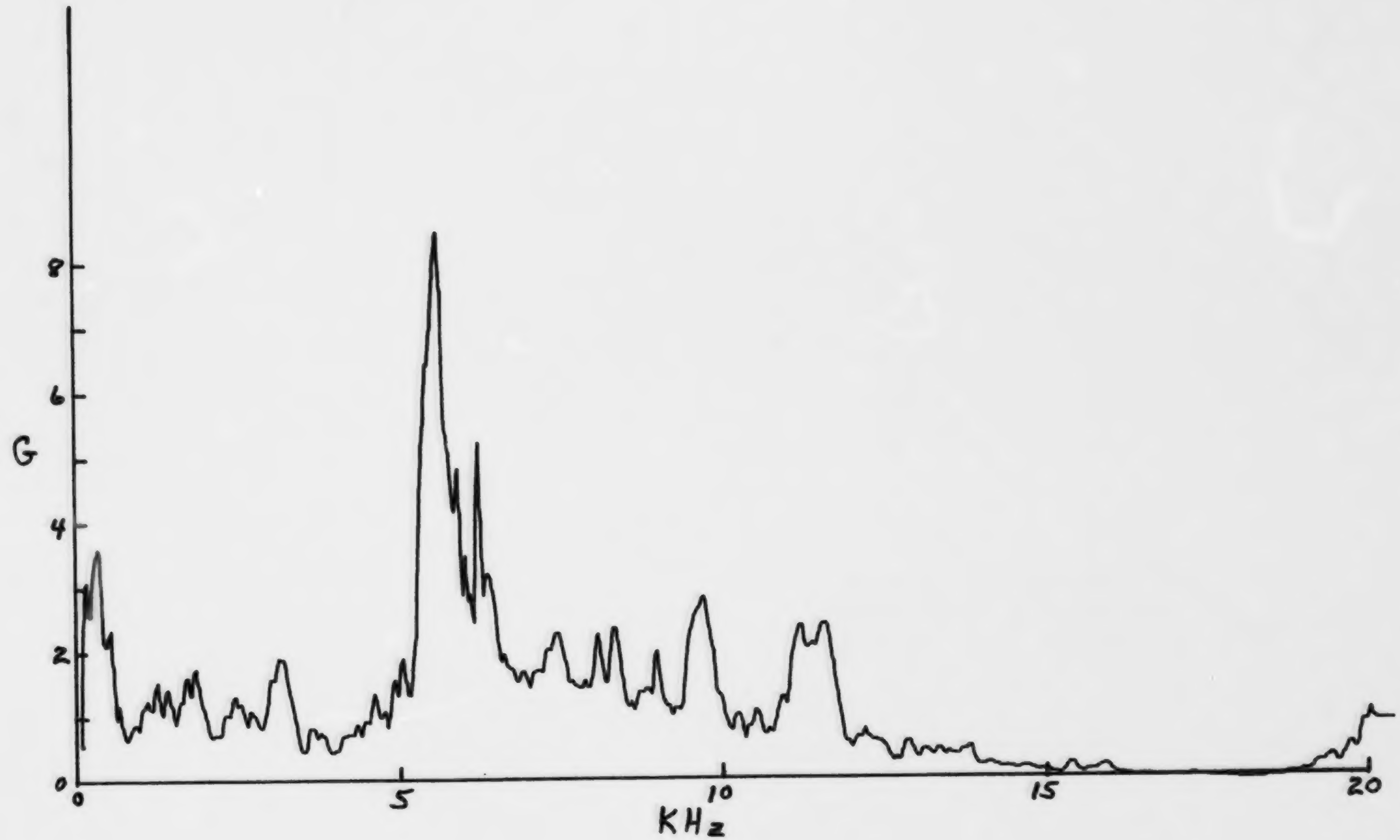
P1-6

P1 - 6   2.3 L, 4 cyl.
Rear Block, C90, 2600 RPM
VL Knock to NK (TI 160/190)



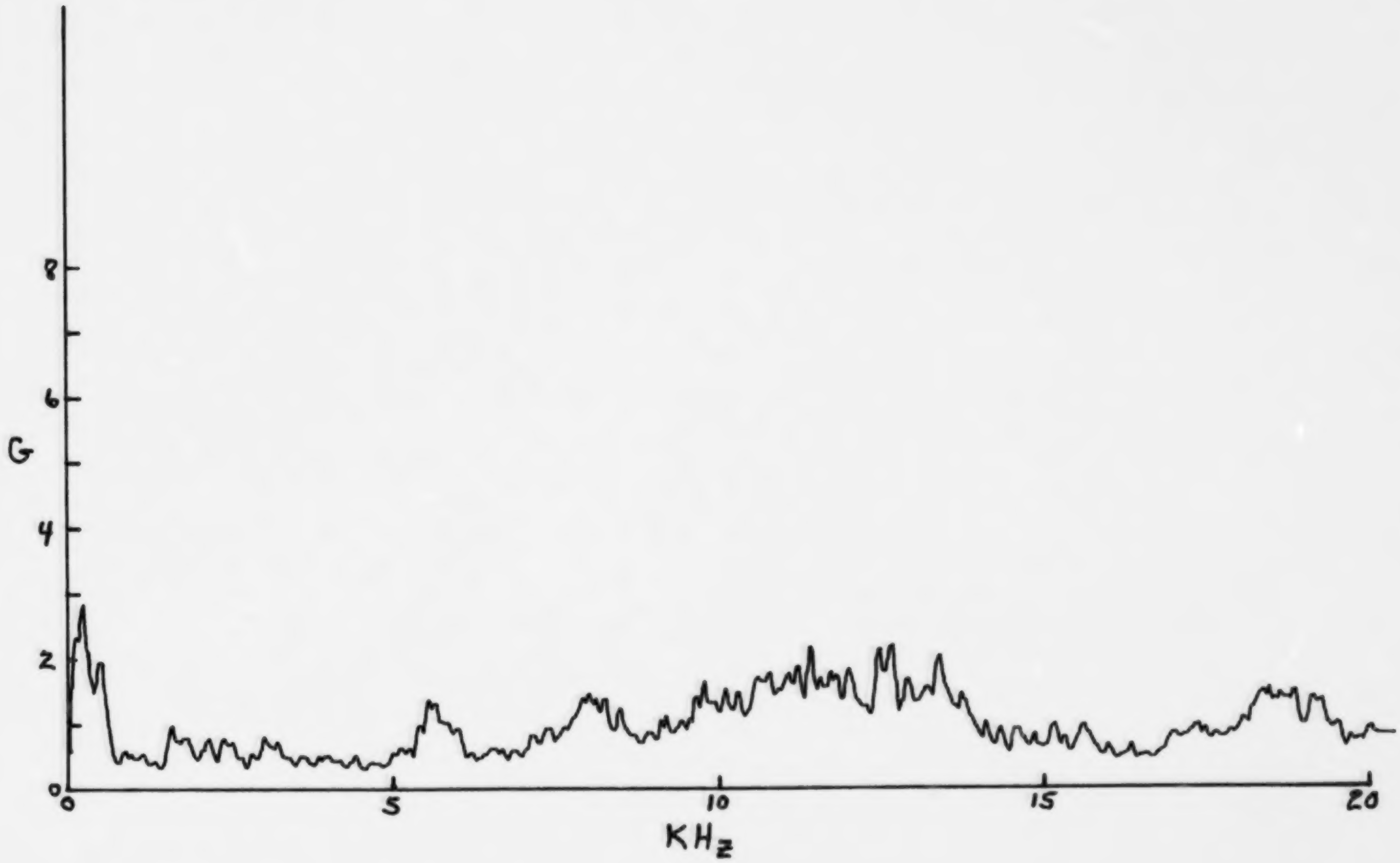
Pl-7

Pl - 7   2.3 L, 4 cyl.
Right Front Head, C90, 2600
RPM VL Knock to NK (TI 160/190)



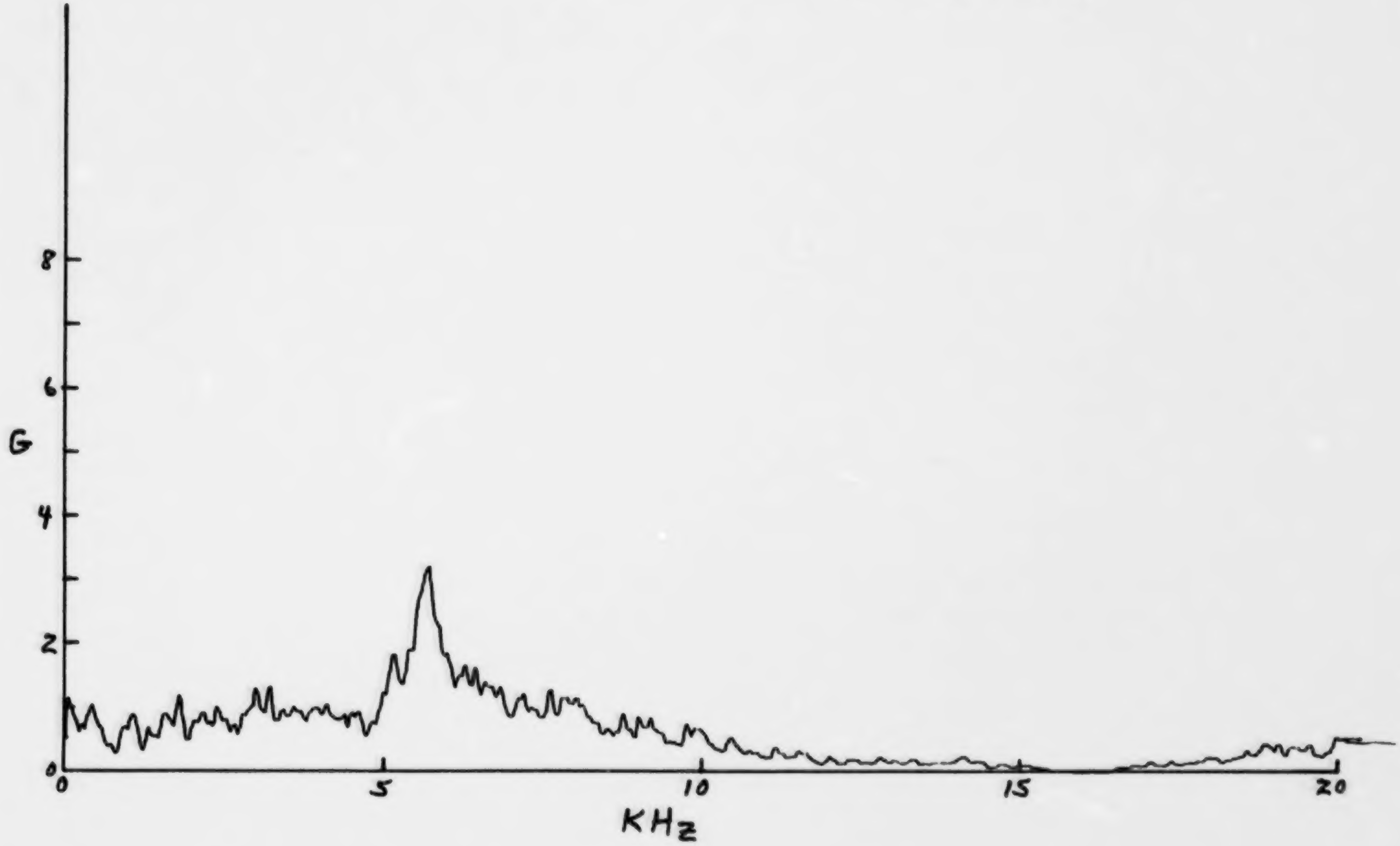
P2-5

P2 - 5   2.3 L, 4 cyl.
Rear Head, C90, 2600 RPM
NK to VL (TI 380/405)



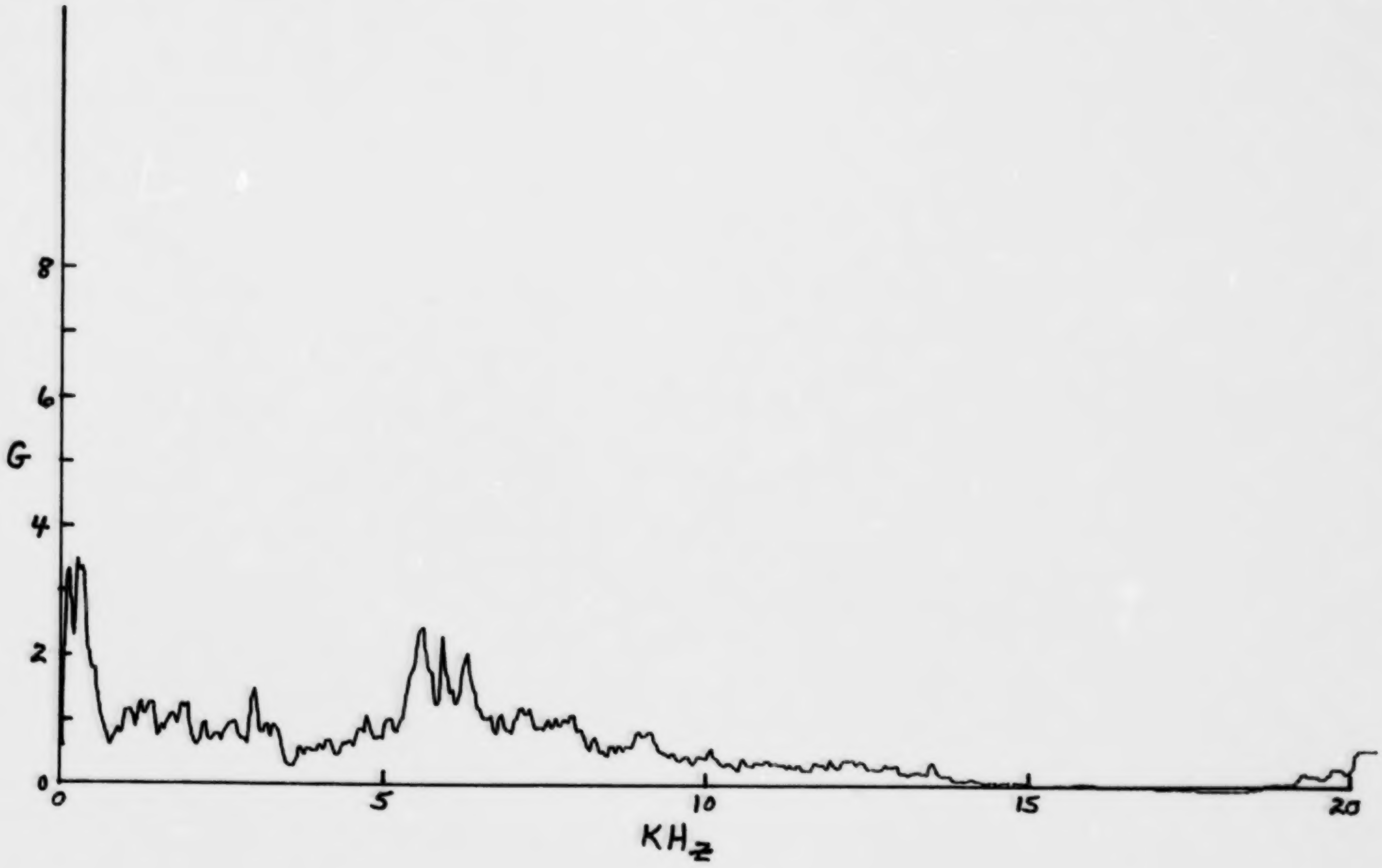
P2-6

P2 - 6   2.3 L, 4 cyl.
Rear Block, C90, 2600 RPM
NK to VL (TI 380/405)



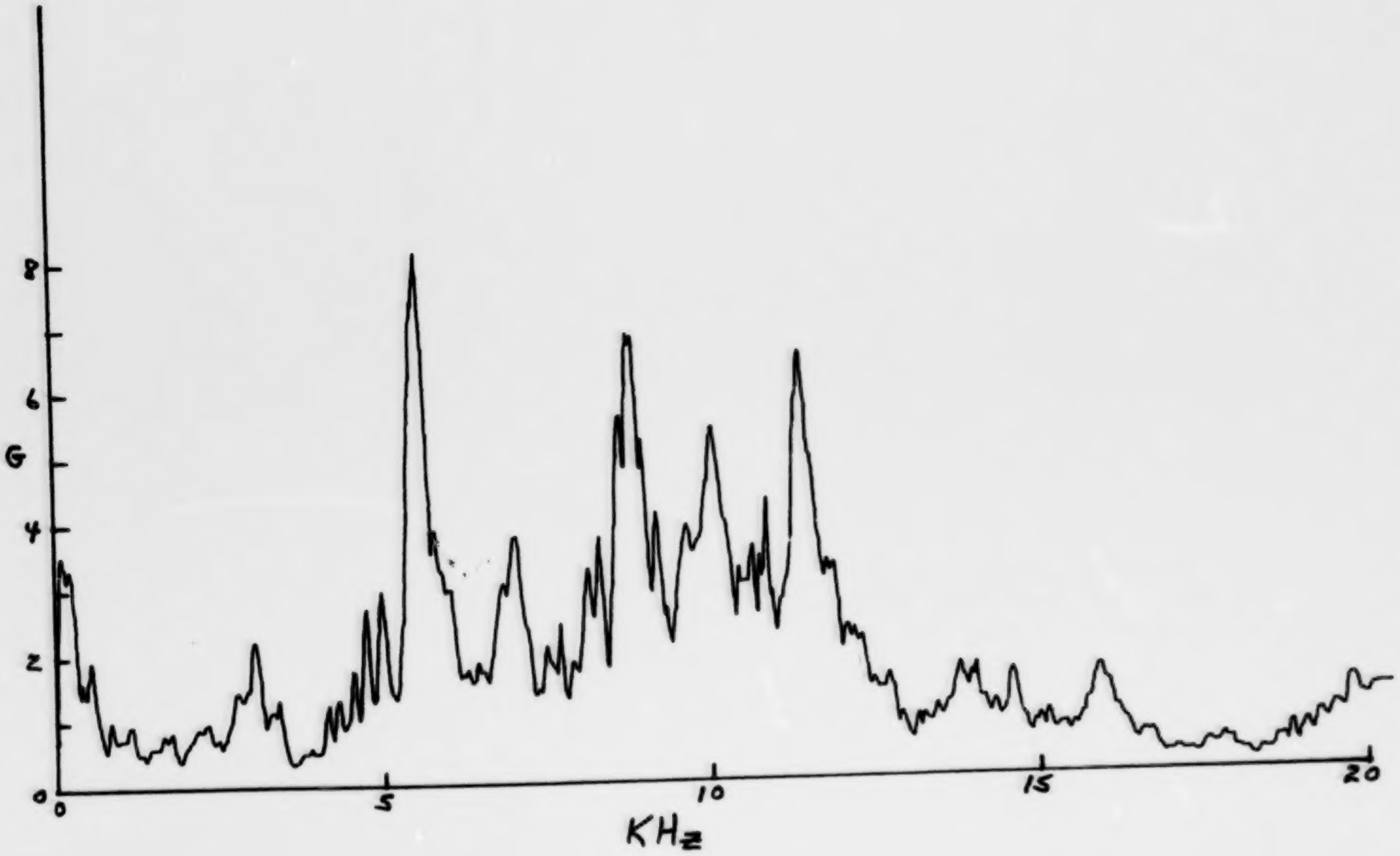
P2-7

P2 - 7   2.3 L, 4 cyl.
Right Front Head, C90, 2600
RPM NK to VL (TI 380/405)



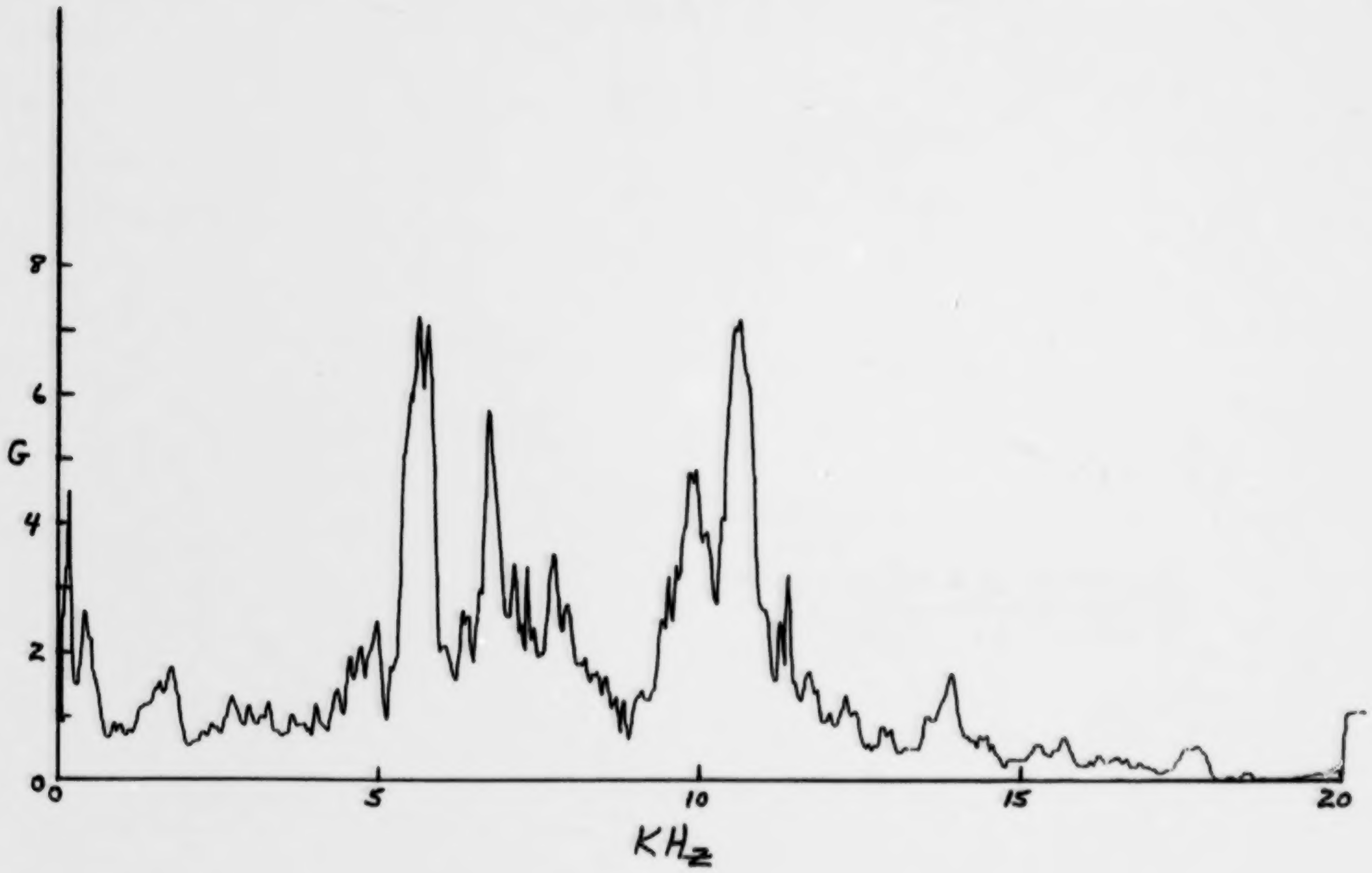
P3-5

P3 - 5 2.3 L, 4 cyl.
Intake Manifold, C90, 2600
RPM NK to VL (TI 685/706)



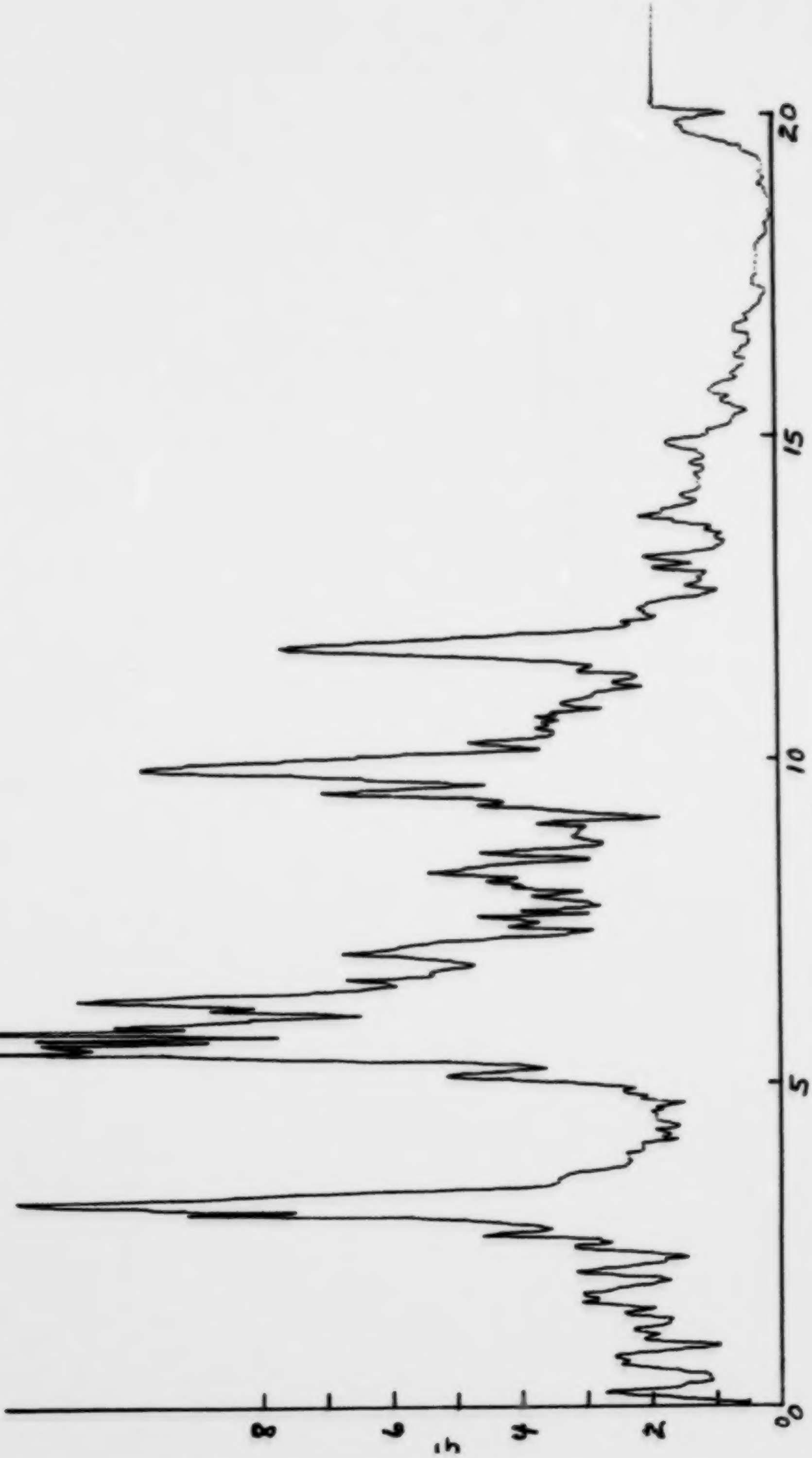
P3-6

P3 - 6   2.3 L, 4 cyl.
Right Rear Head, C90, 2600
RPM NK to VL (TI 685/706)



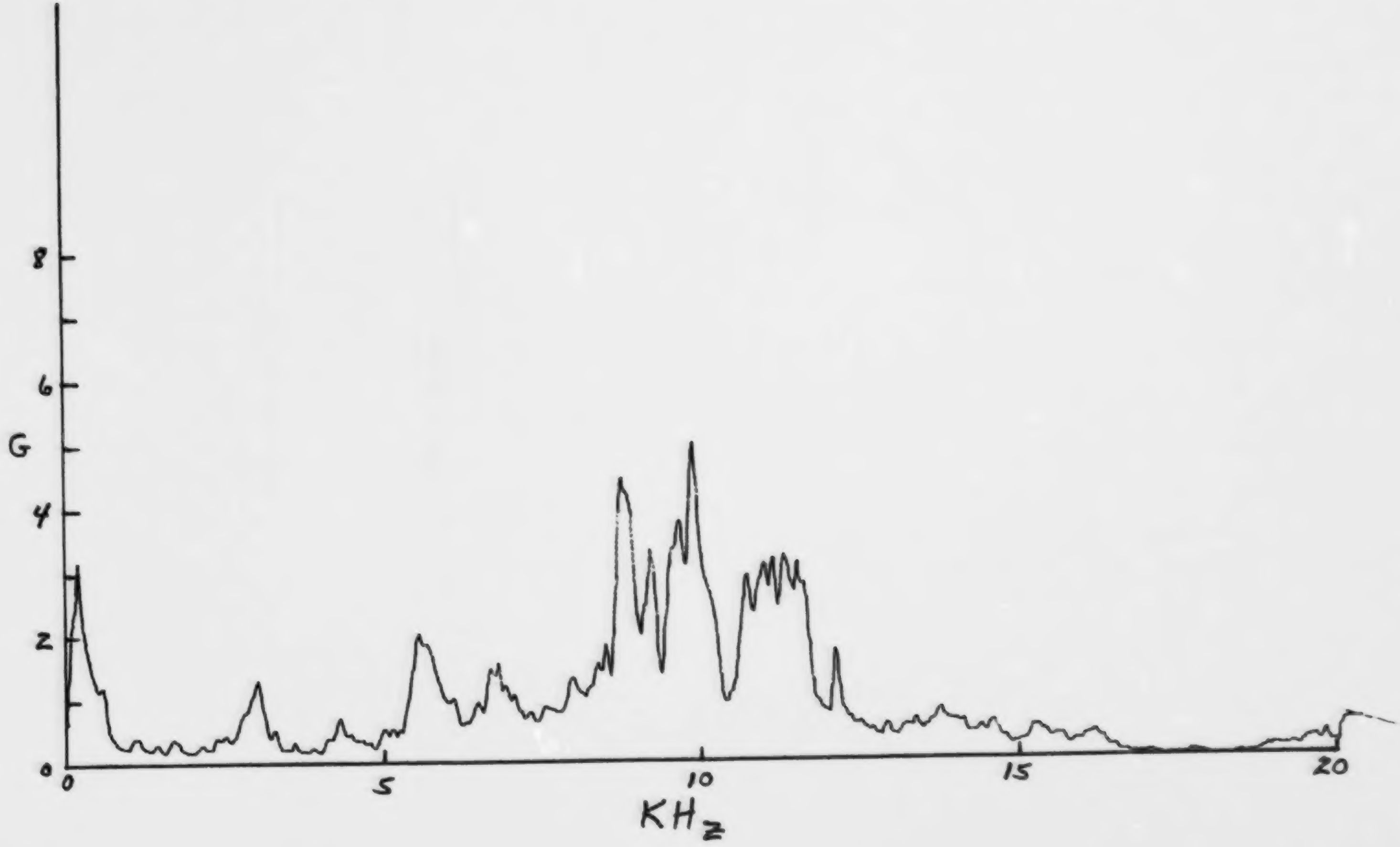
P3-7

P3 - 7 2.3 L, 4 cyl.
Right Front Block, C90, 2600
RPM NK to VL (TI 685/706)



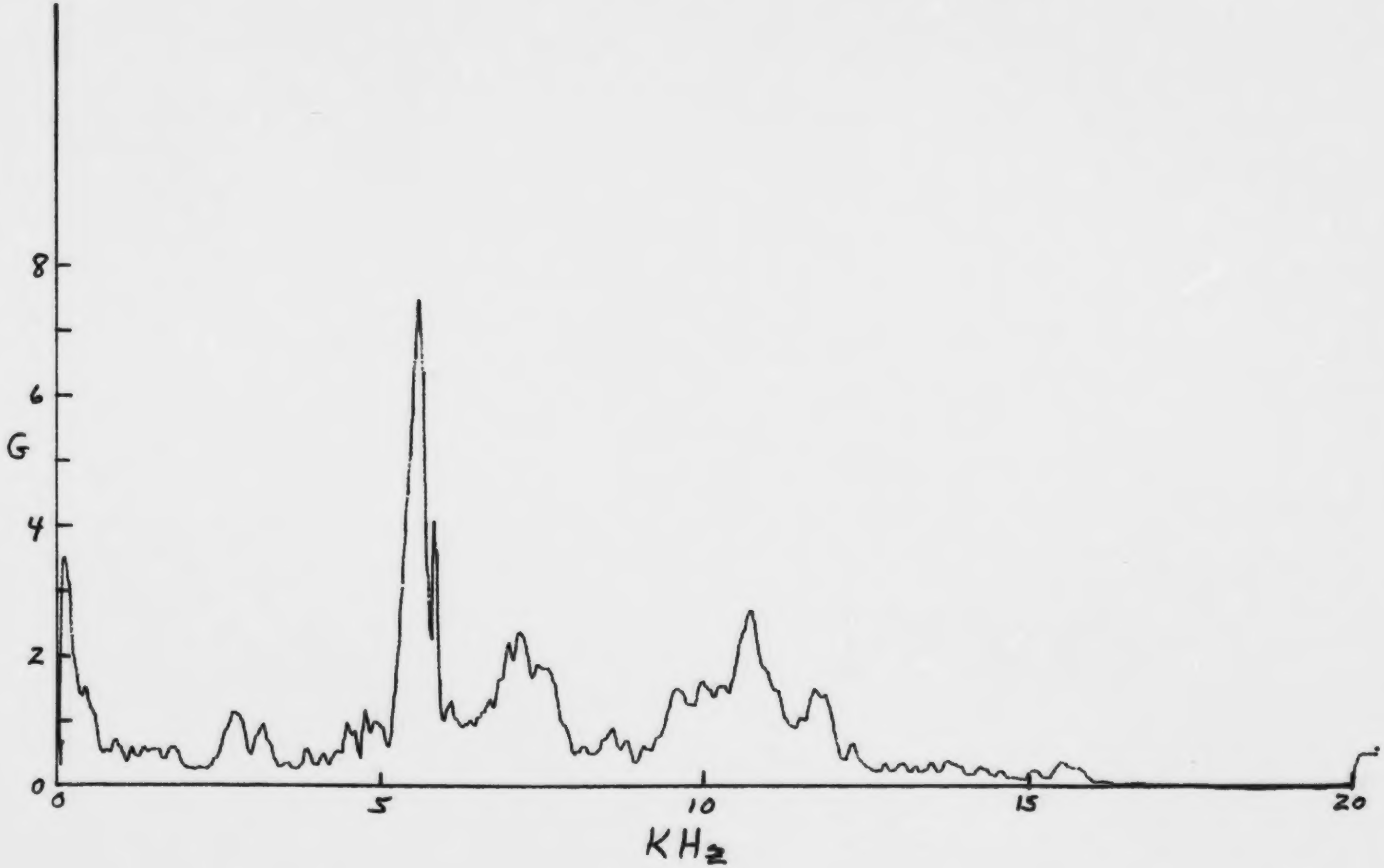
P4-5

P4 - 5   2.3 L, 4 cyl.
Intake Manifold, C90, 1600
RPM VL to NK (TI 870/888)



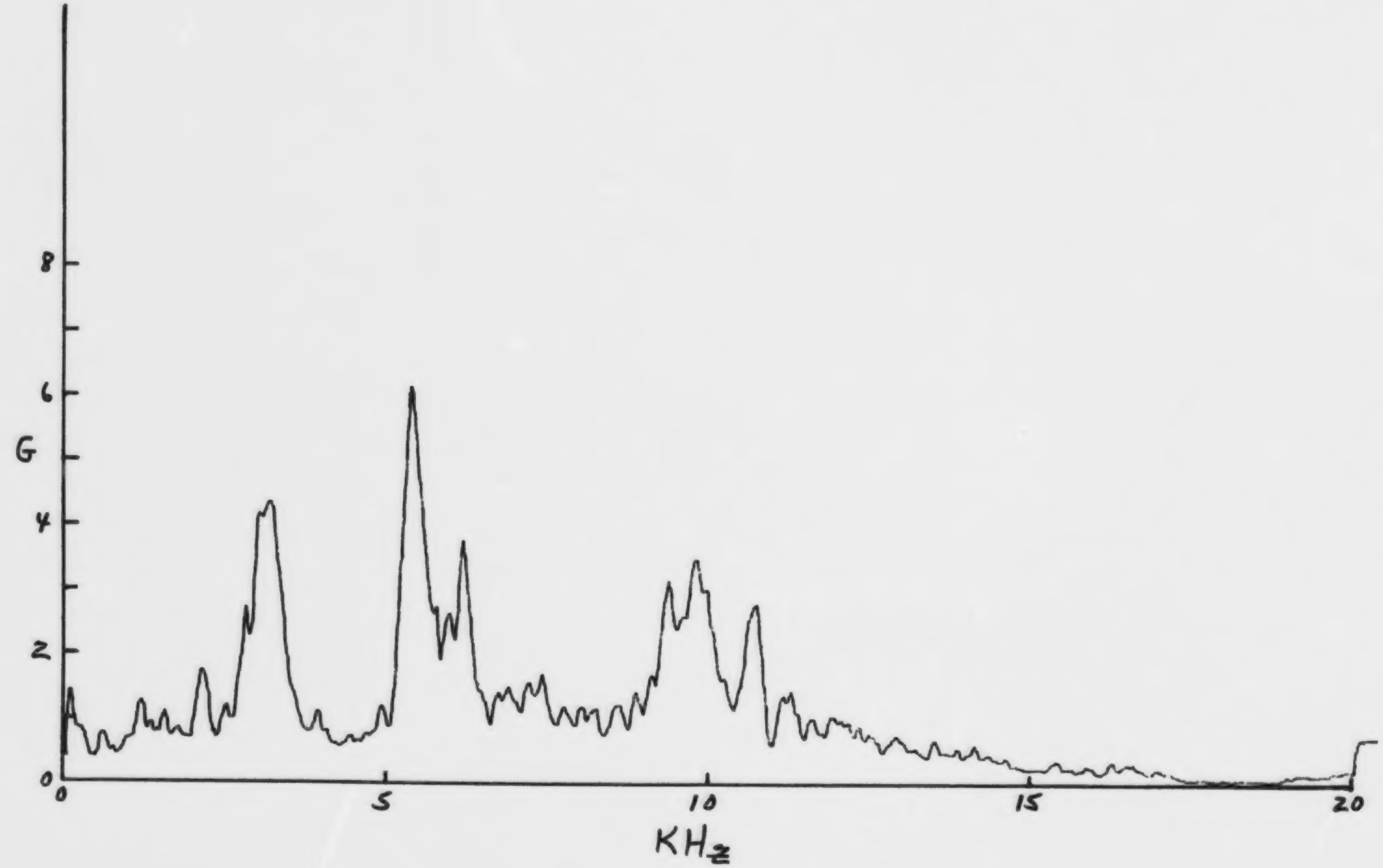
P4-6

P4 - 6   2.3 L, 4 cyl.
RRH, C90, 1600 RPM
VL to NK (TI 870/888)



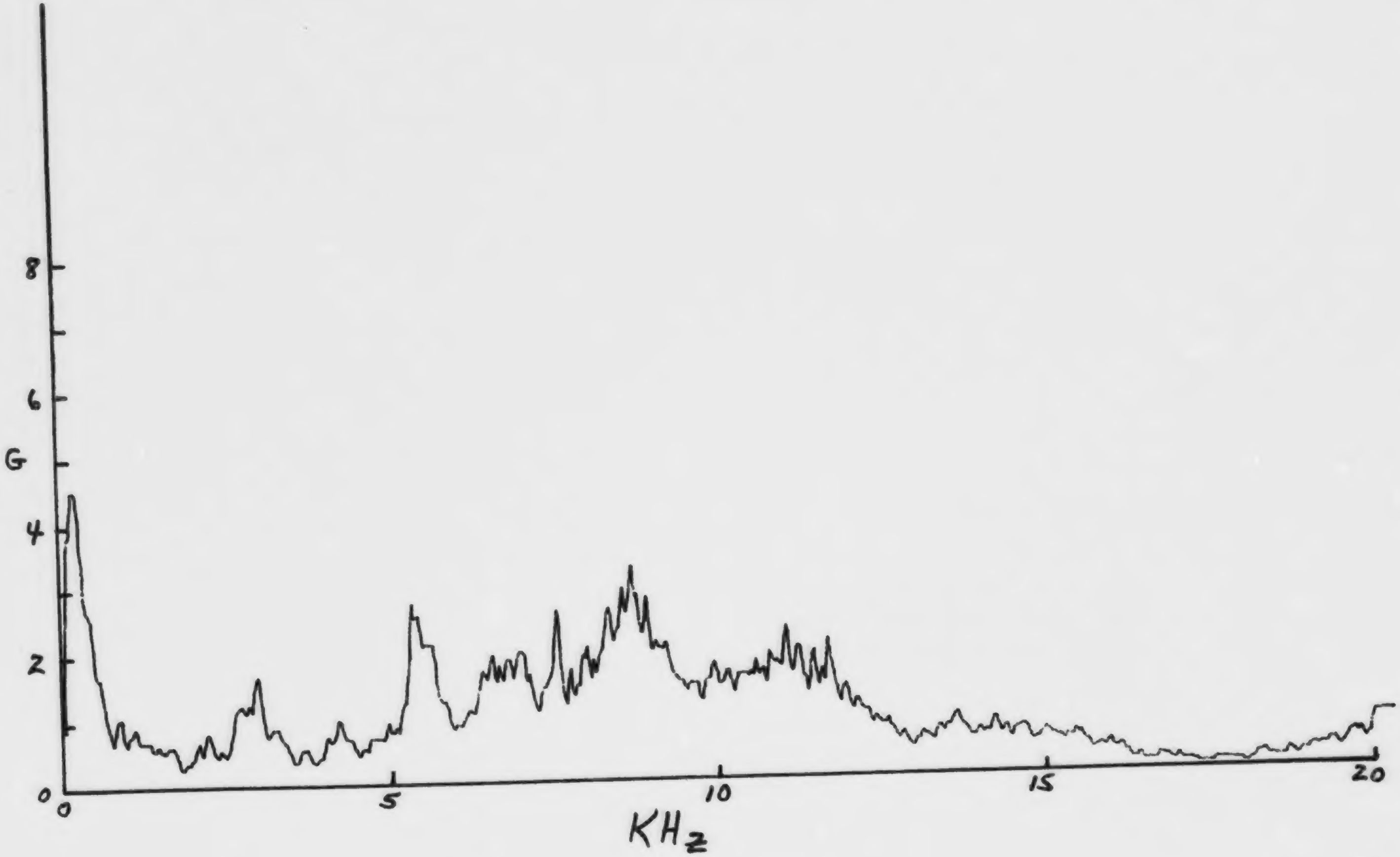
P4-7

P4 - 7   2.3 L, 4 cyl.
RFB, C90, 1600 RPM
VL to NK (TI 870/888)

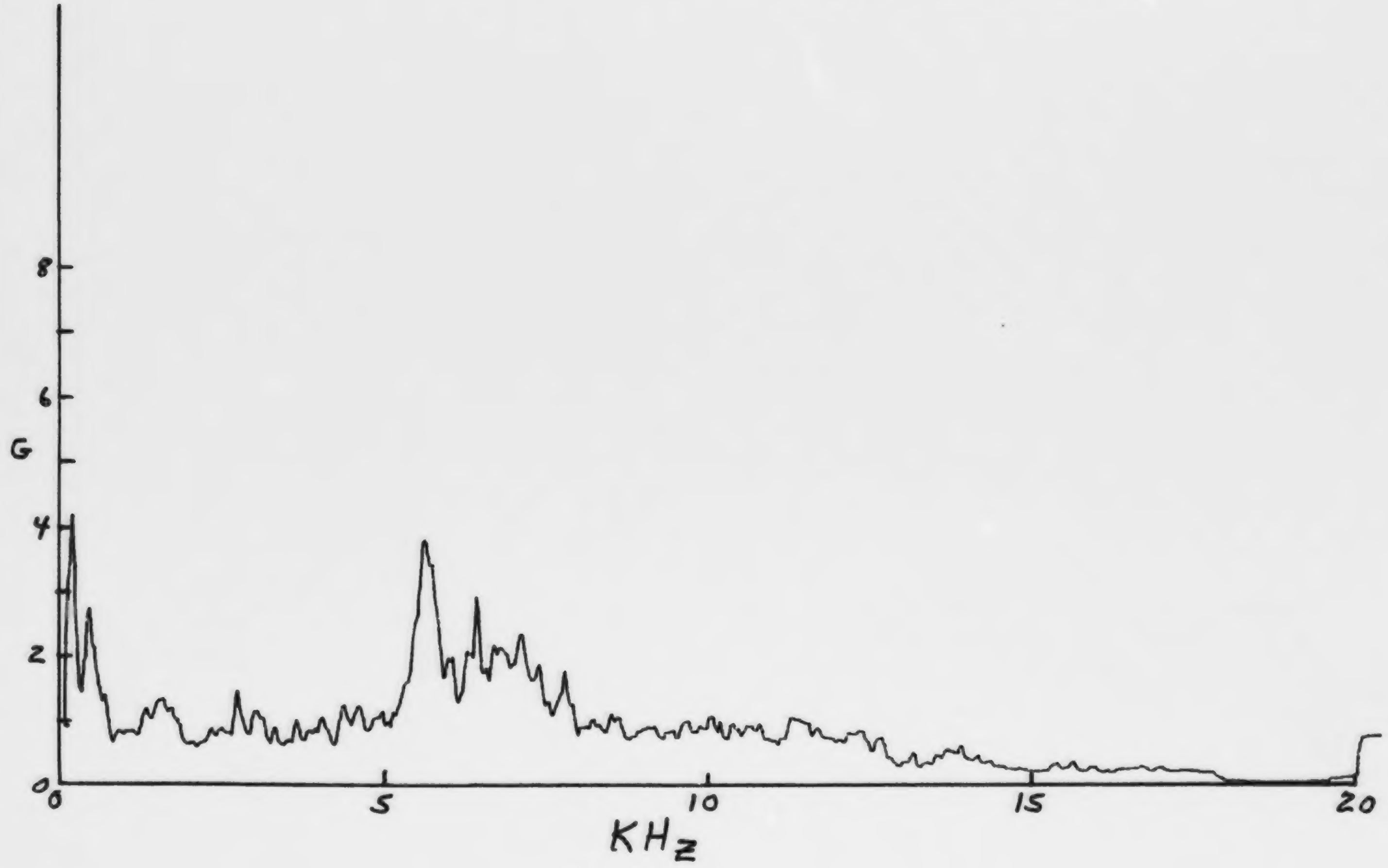


P5-5

P5 - 5   2.3 L, 4 cyl.
Intake Manifold, C90, 2600
RPM No Knock to VL (TI 820/840)

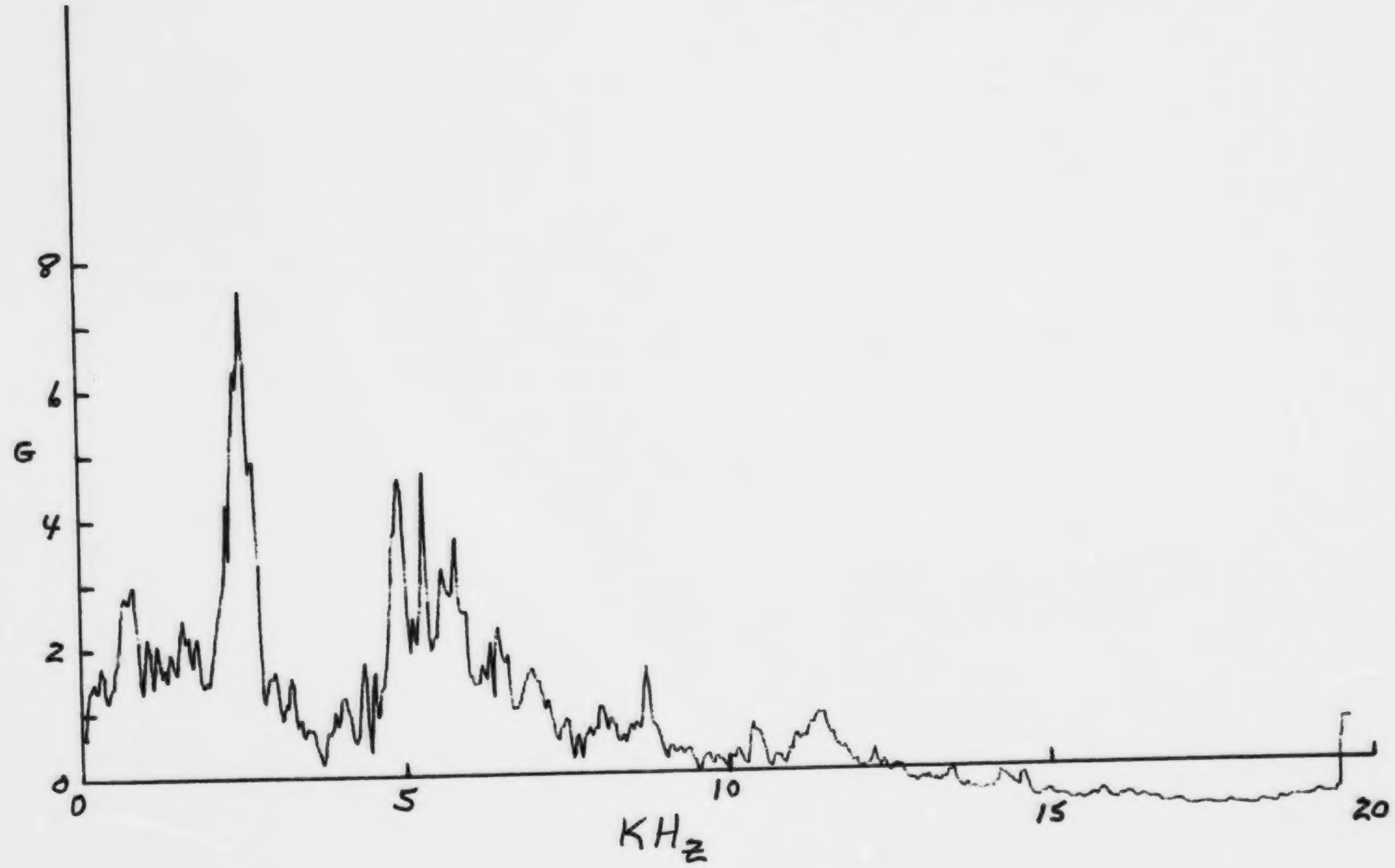


P5 - 6   2.3 L, 4 cyl.
Right Rear Head, C90, 2600
RPM NK to VL (TI 820/840)



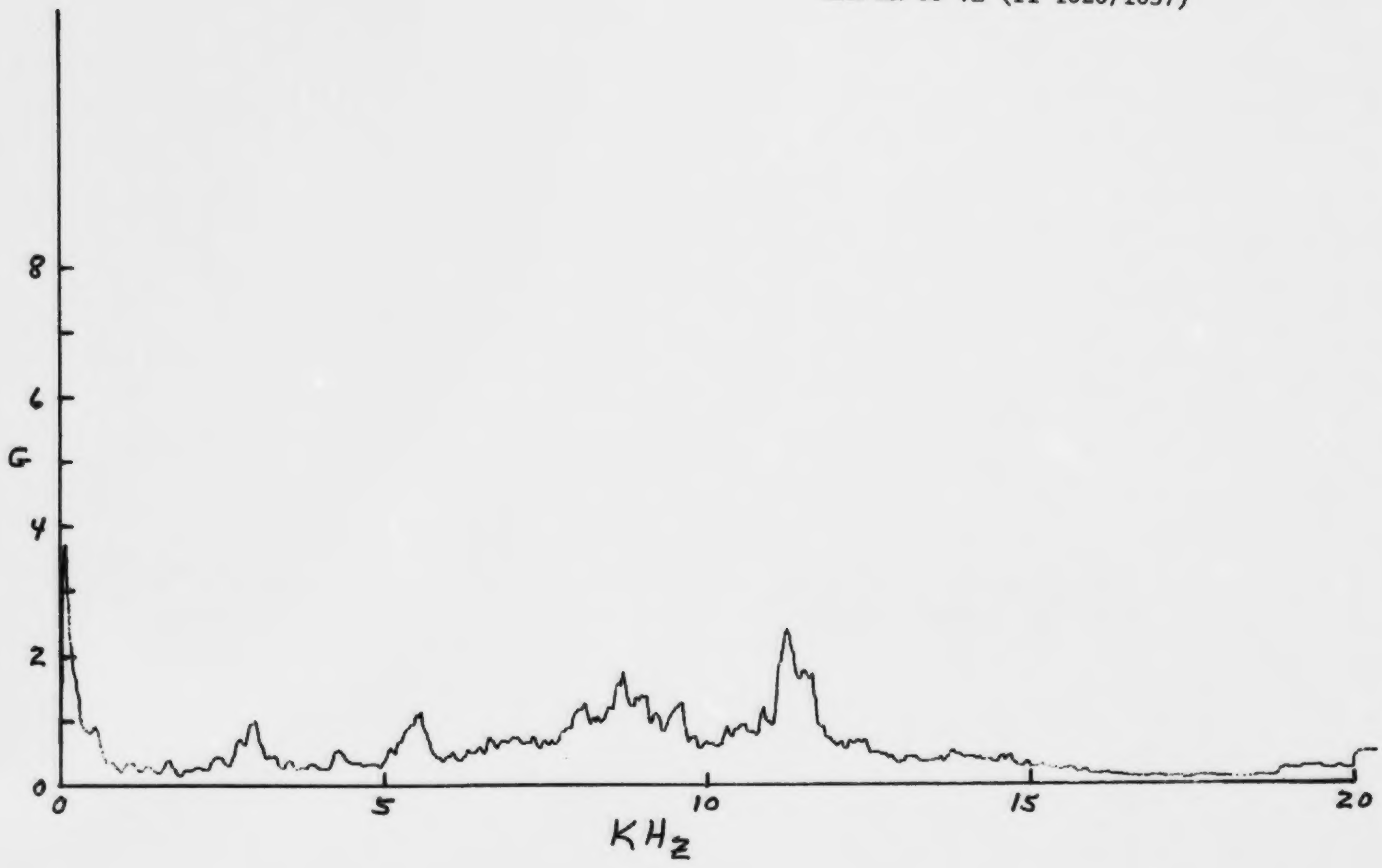
P5-7

P5 - 7   2.3 L, 4 cyl.
Right Front Block, C90, 2600
RPM NK to VL (TI 820/840)



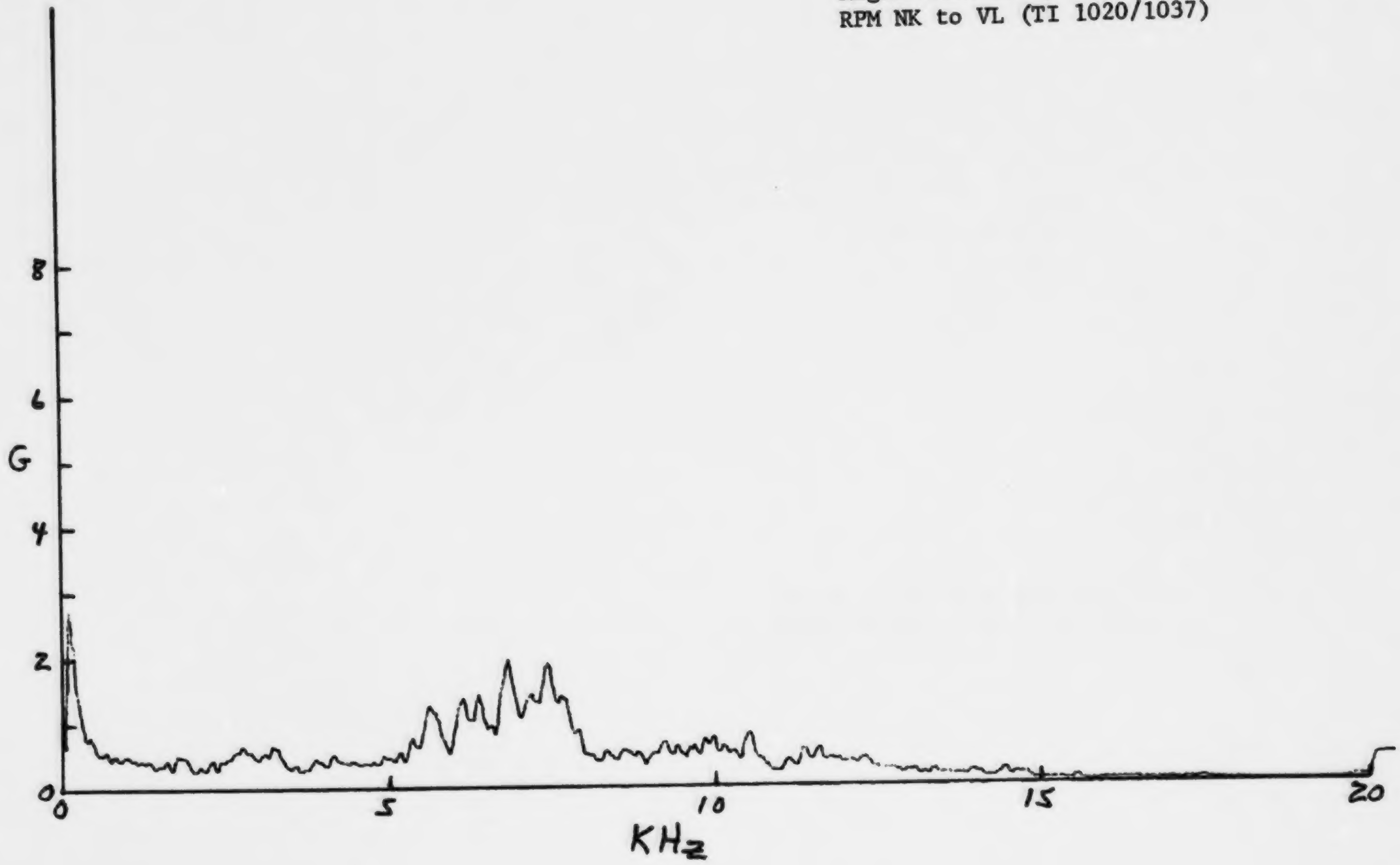
P6-5

P6 - 5   2.3 L, 4 cyl.
Intake Manifold, C90, 1600
RPM NK to VL (TI 1020/1037)



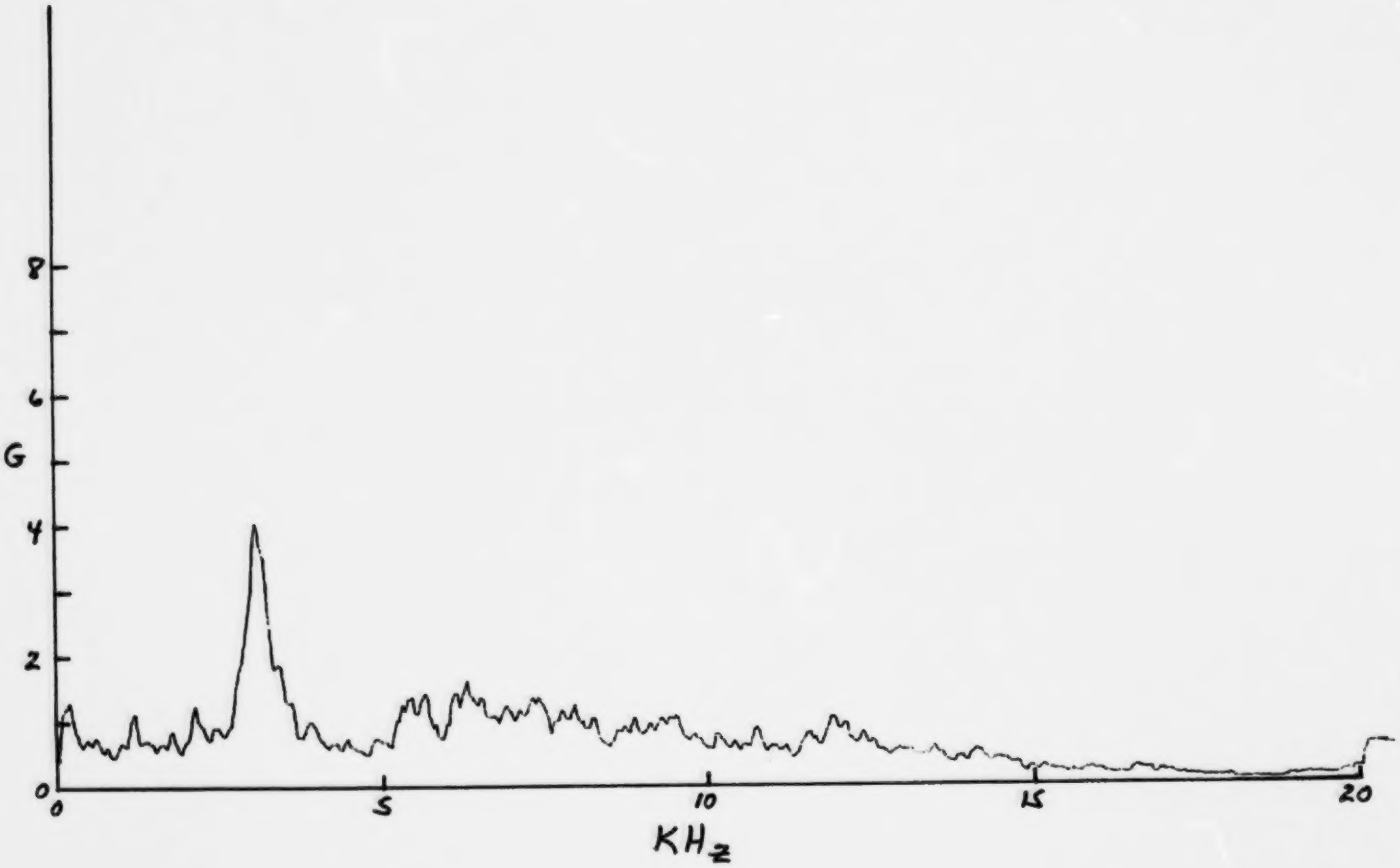
P6-6

P6 - 6   2.3 L, 4 cyl.
Right Rear Head, C90, 1600
RPM NK to VL (TI 1020/1037)



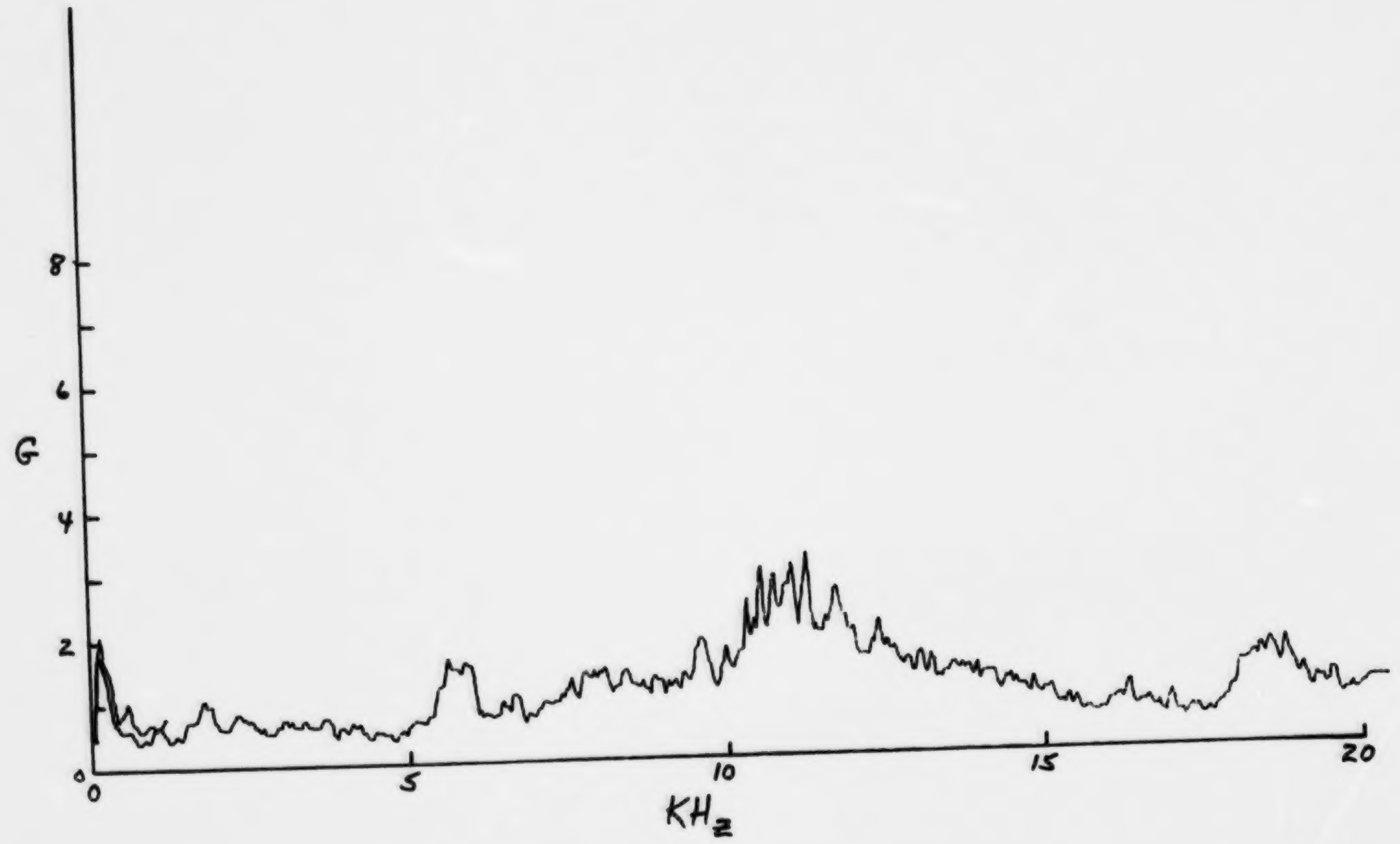
P6-7

P6 - 7 2.3 L, 4 cyl.
Right Front Block, C90, 1600
RPM NK to VL (TI 1020/1037)



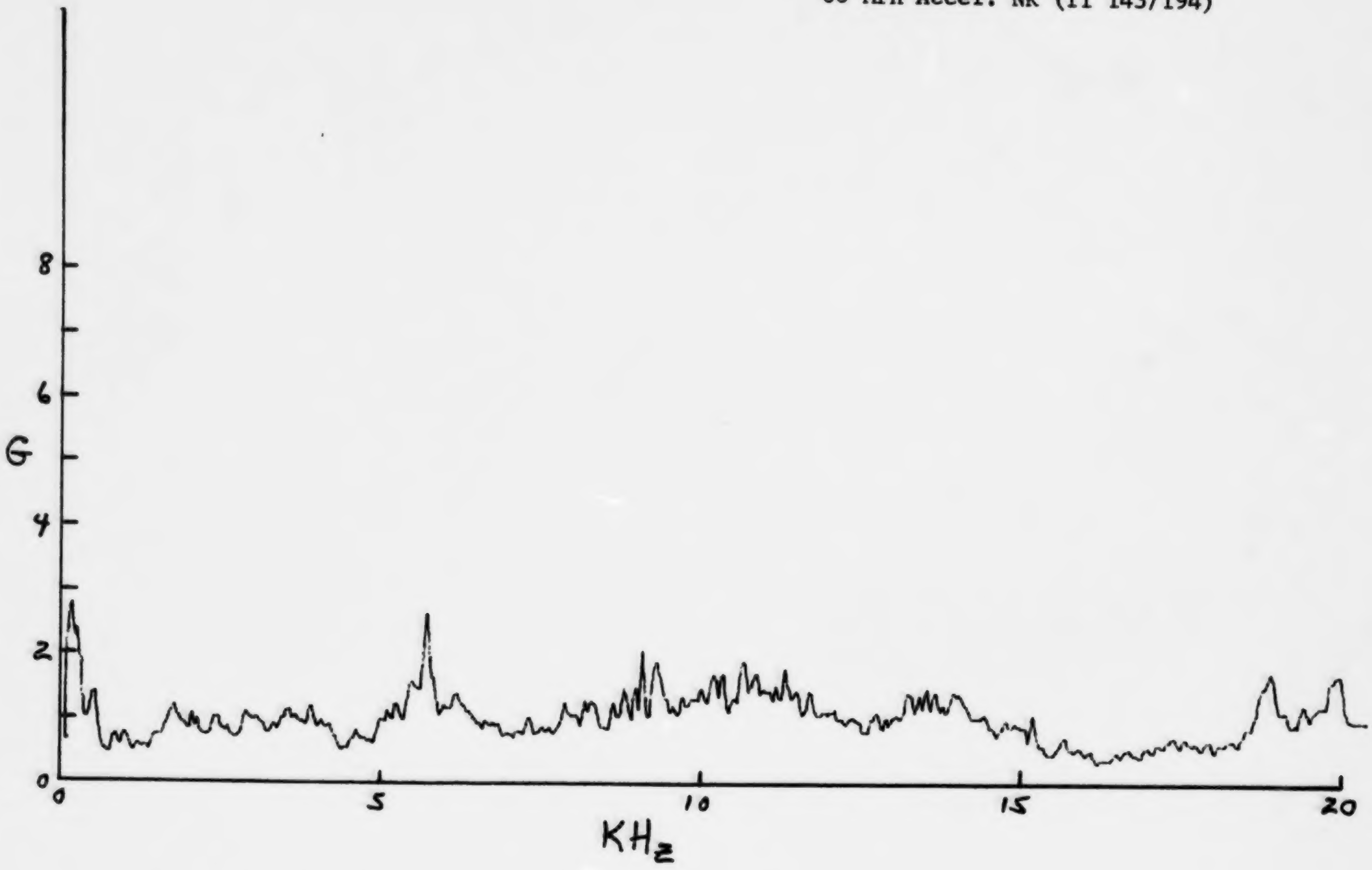
P10-5

P10 - 5   2.3 L, 4 cyl.
Rear Head, Iso-Octane, 30 to
60 MPH Accel. NK (TI 143/194)



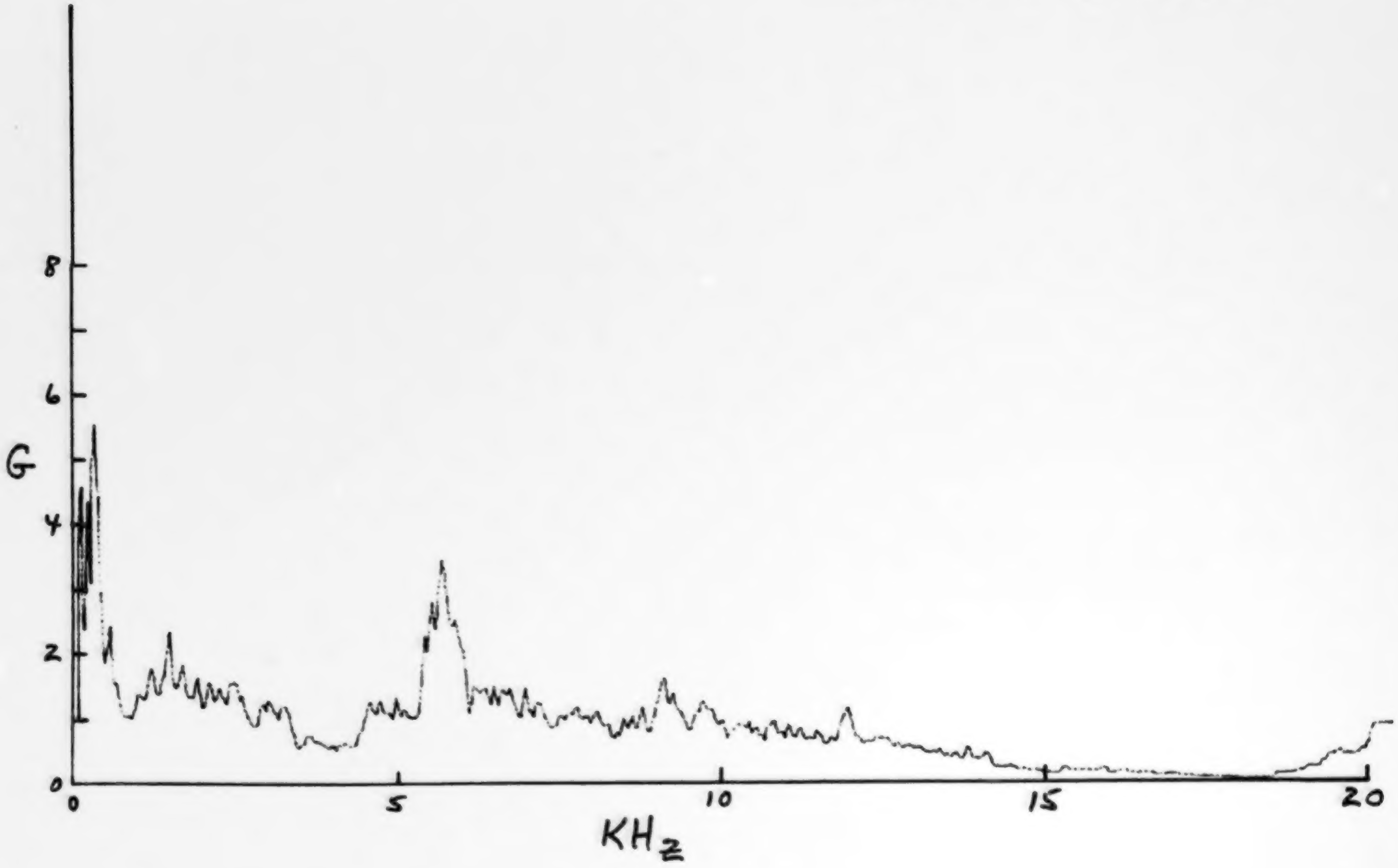
P10-6

P10 - 6   2.3 L, 4 cyl.
Rear Block, Iso-Octane, 30 to
60 MPH Accel. NK (TI 143/194)



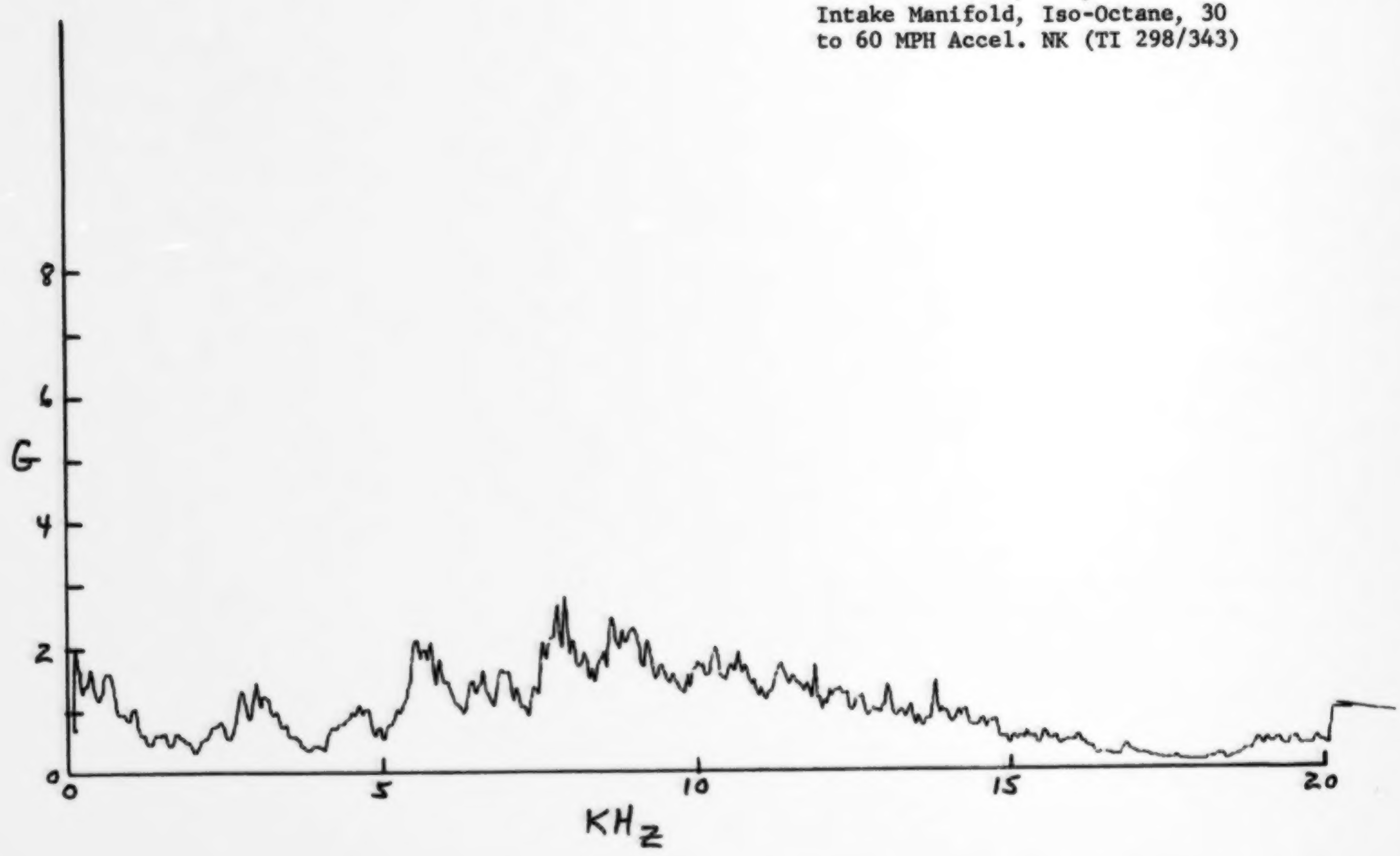
P10-7

P10 - 7   2.3 L, 4 cyl.
Right Front Head, Iso-Octane, 30
to 60 MPH Accel. NK (TI 143/194)



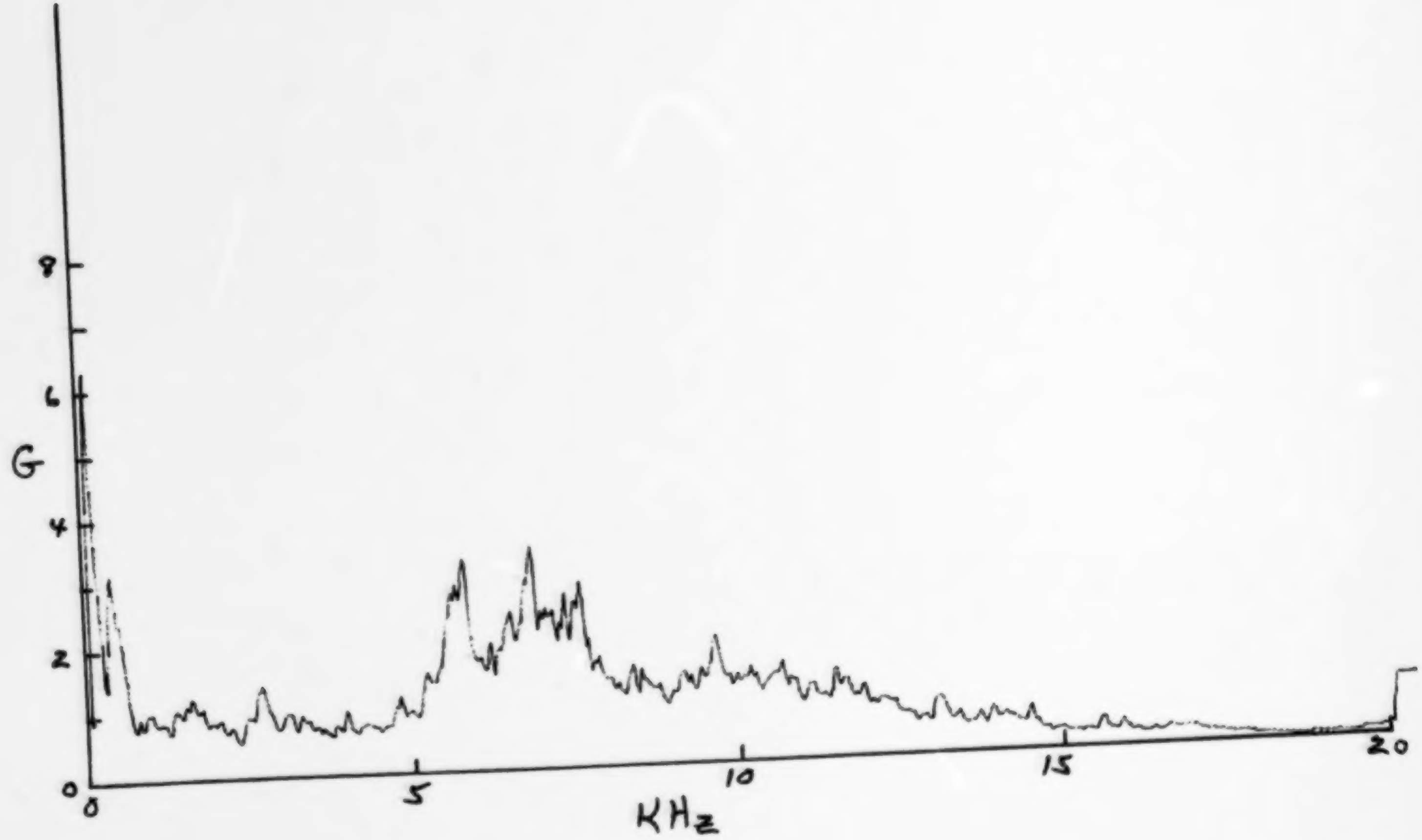
P11-5

P11 - 5   2.3 L, 4 cyl.
Intake Manifold, Iso-Octane, 30
to 60 MPH Accel. NK (TI 298/343)

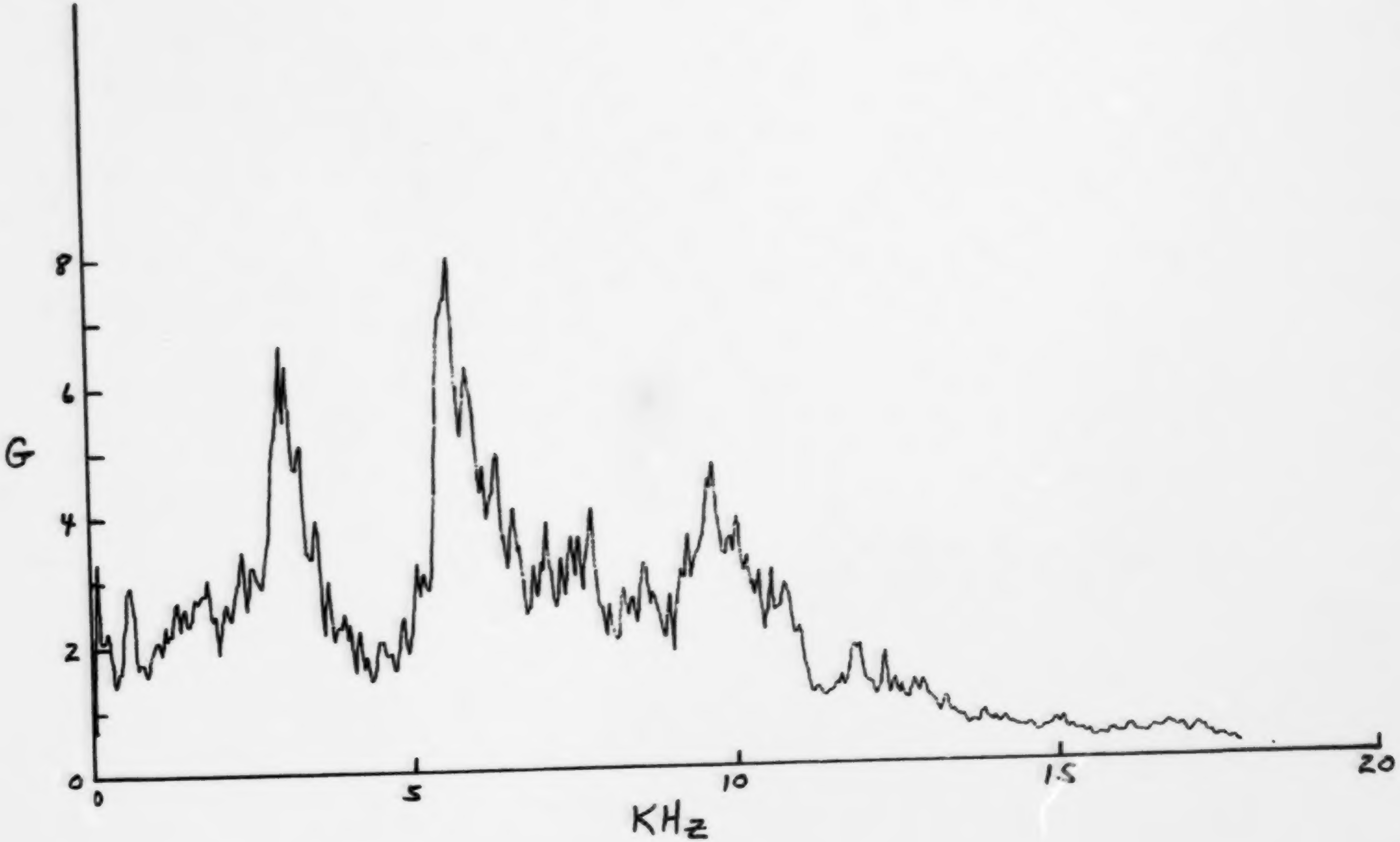


P11 - 6

P11 - 6   2.3 L, 4 cyl.
Right Rear Head, Iso-Octane, 30
to 60 MPH Accel. NK (TI 298/343)



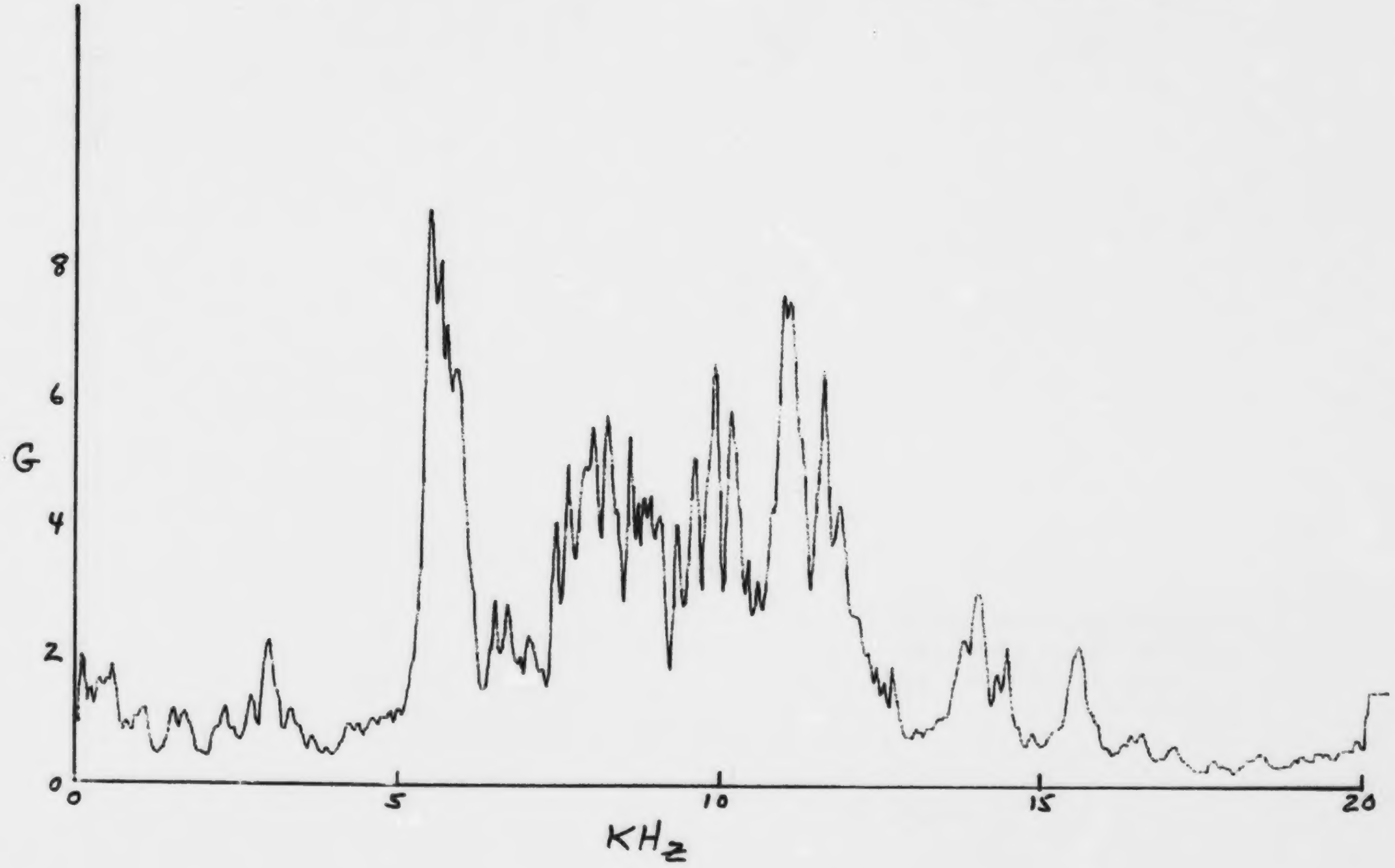
P11-7



P11 - 7 2.3 L, 4 cyl.
Right Front Block, Iso-Octane, 30 to 60 MPH Accel. NK (TI 298/343)

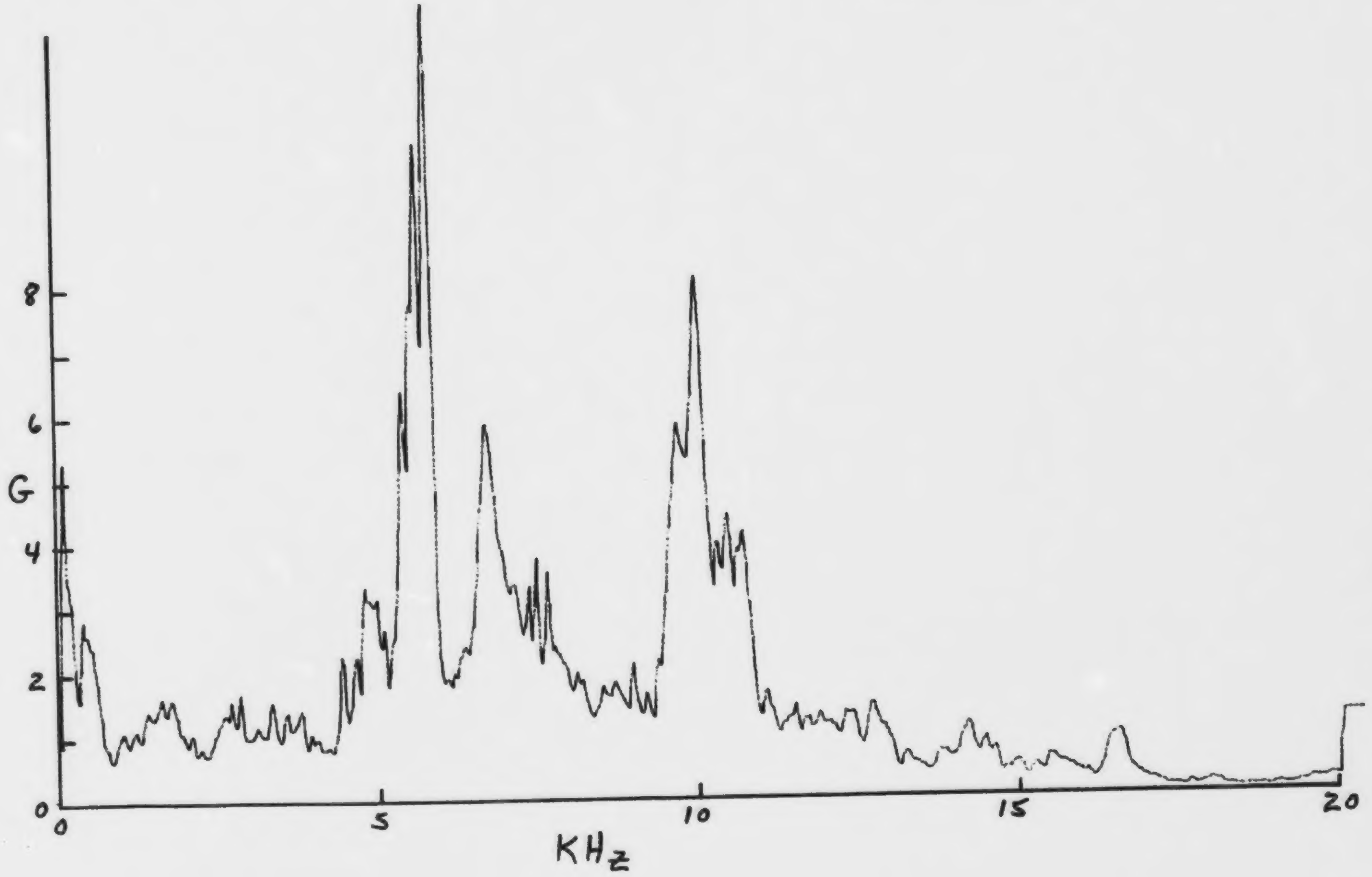
P12 -5

P12 - 5   2.3 L, 4 cyl.
Intake Manifold, C90, 30 to
60 MPH Accel. VL (TI 433/468)

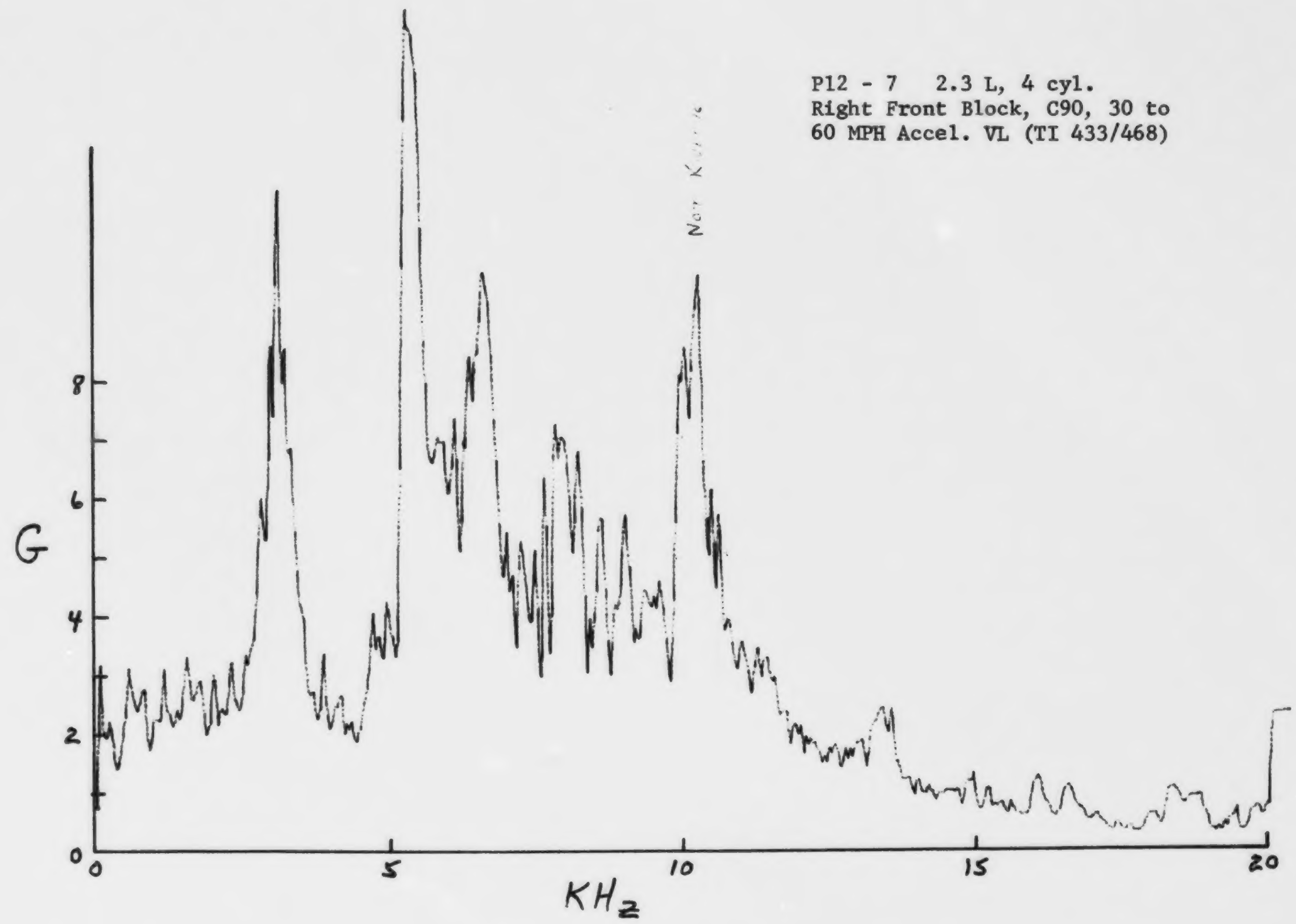


P12-6

P12 - 6   2.3 L, 4 cyl.
Right Rear Head, C90, 30 to
60 MPH Accel. VL (TI 433/468)

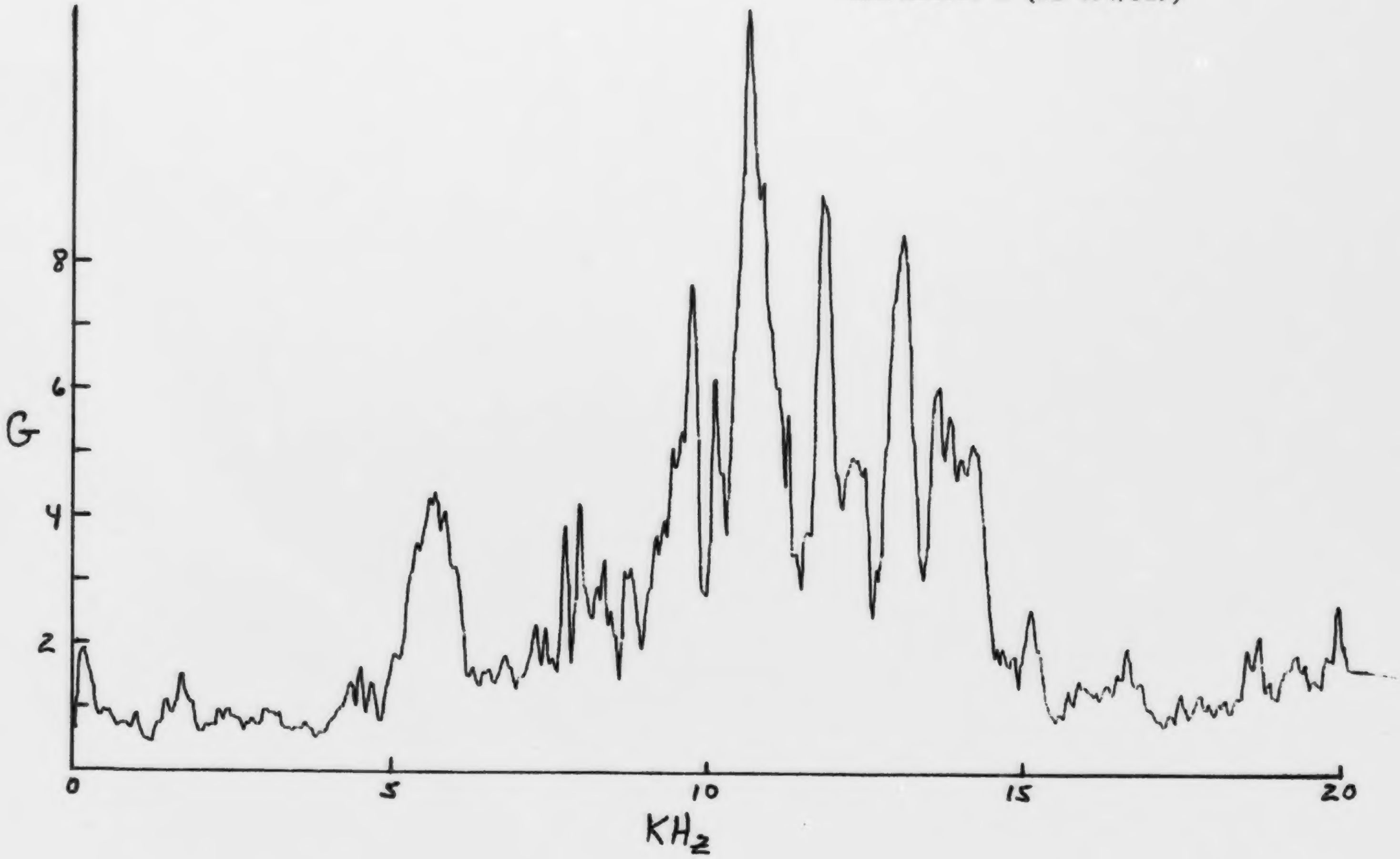


P12-7



P12 - 7 2.3 L, 4 cyl.
Right Front Block, C90, 30 to
60 MPH Accel. VL (TI 433/468)

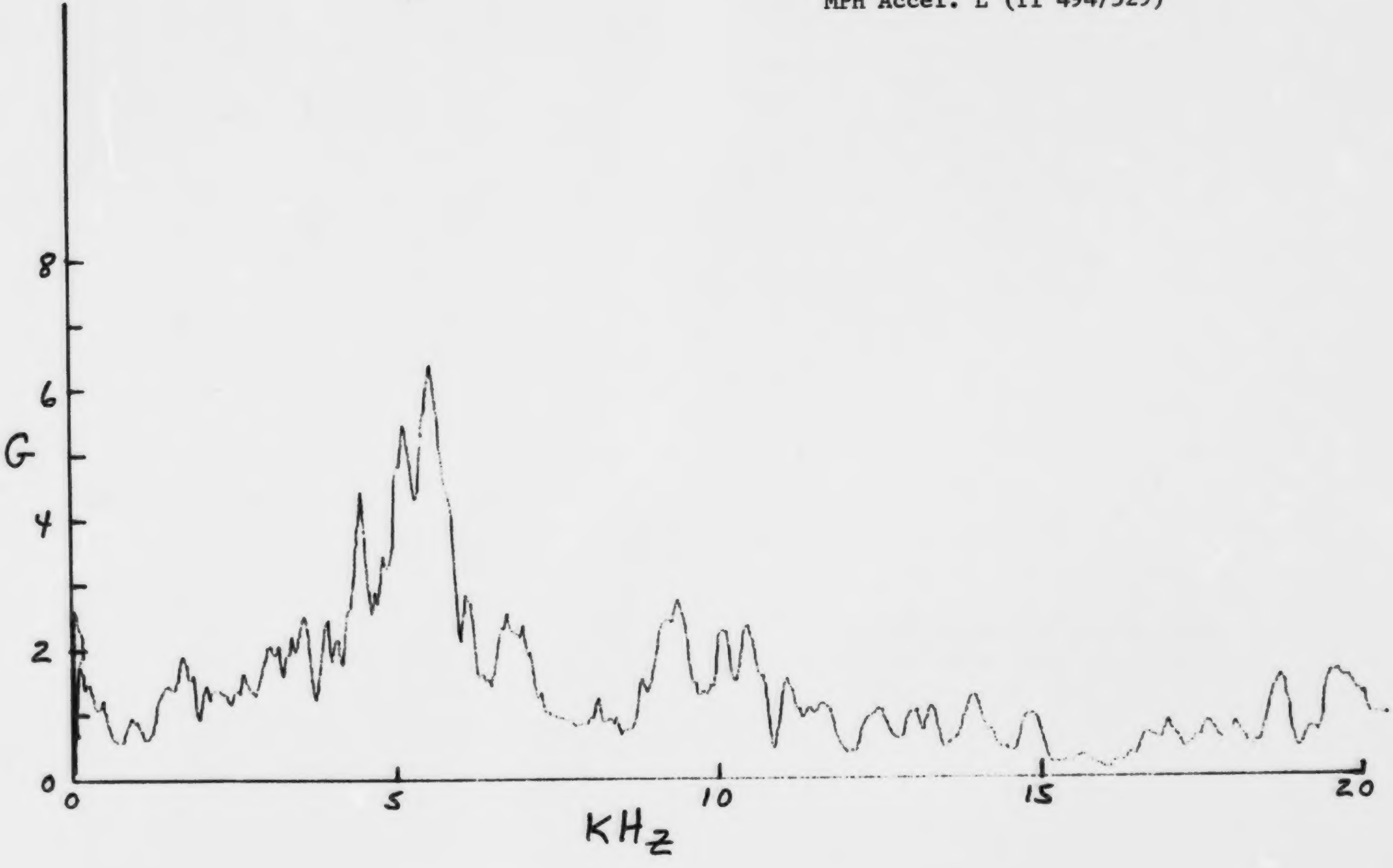
P13-5



P13 - 5   2.3 L, 4 cyl.
Rear Head, C90, 30 to 60
MPH Accel. L (TI 494/529)

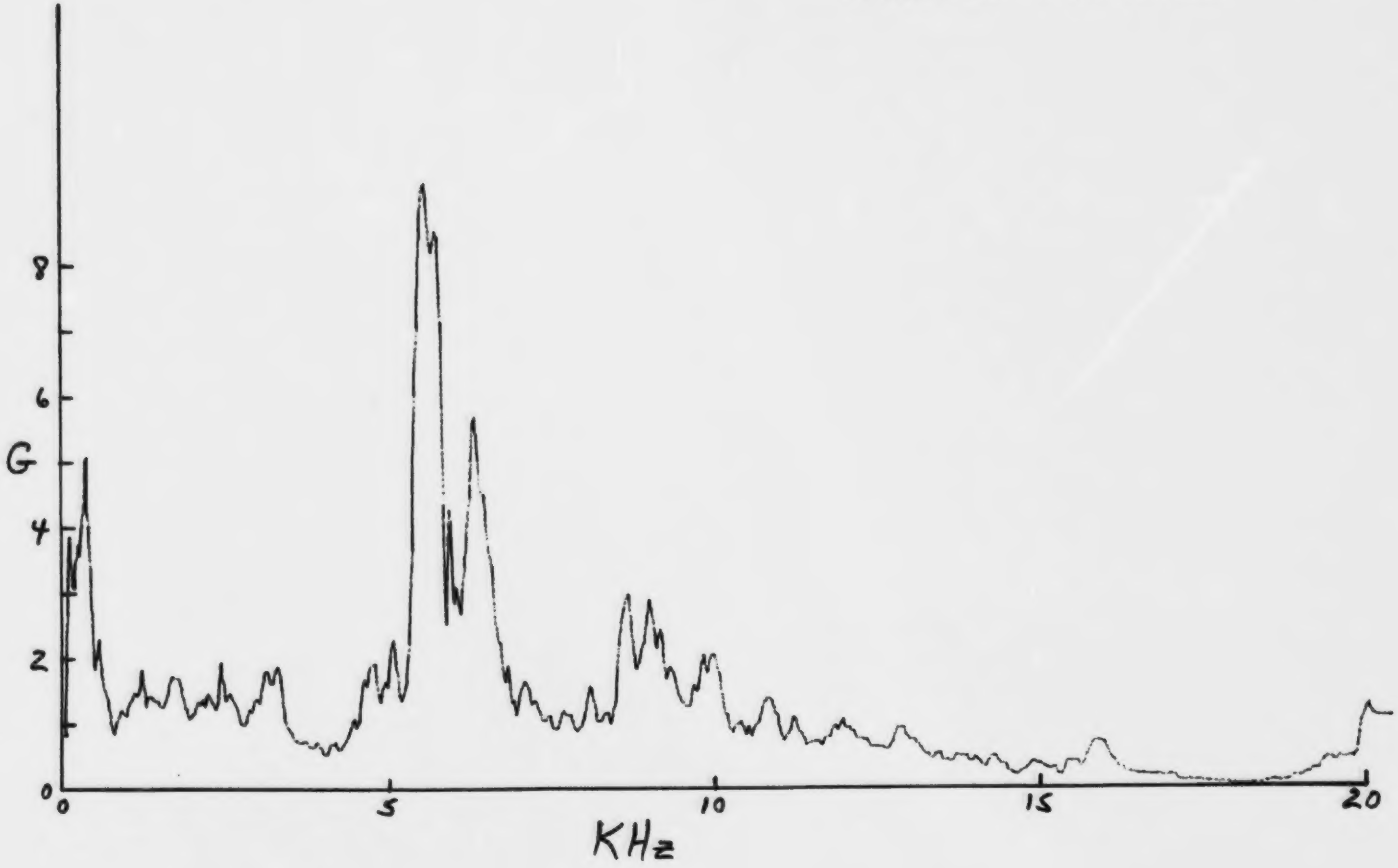
P13-6

P13 - 6   2.3 L, 4 cyl.
Rear Block, C90, 30 to 60
MPH Accel. L (TI 494/529)

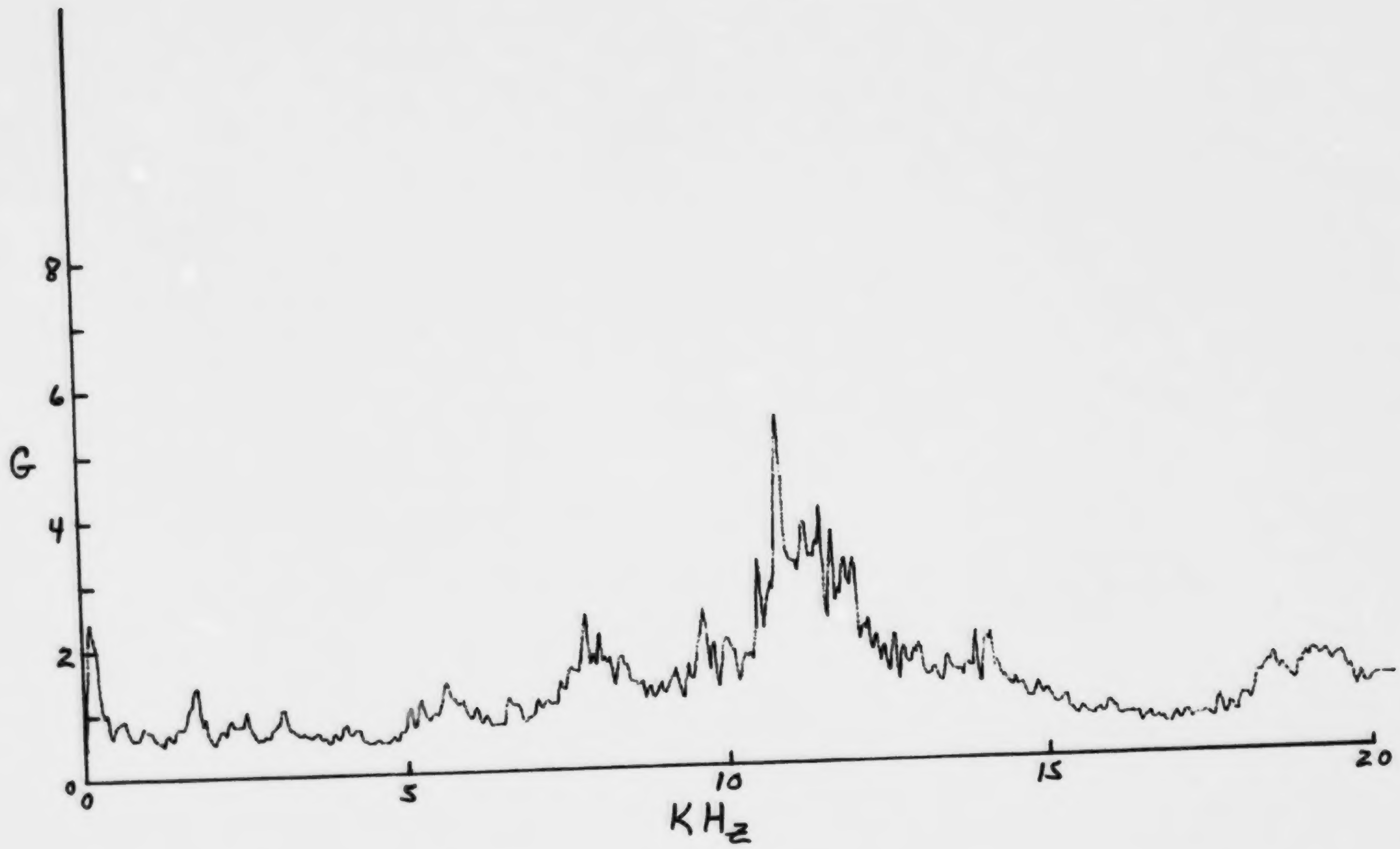


P13-7

P13 - 7   2.3 L, 4 cyl.
Right Front Head, C90, 30 to
60 MPH Accel. L (TI 494/529)

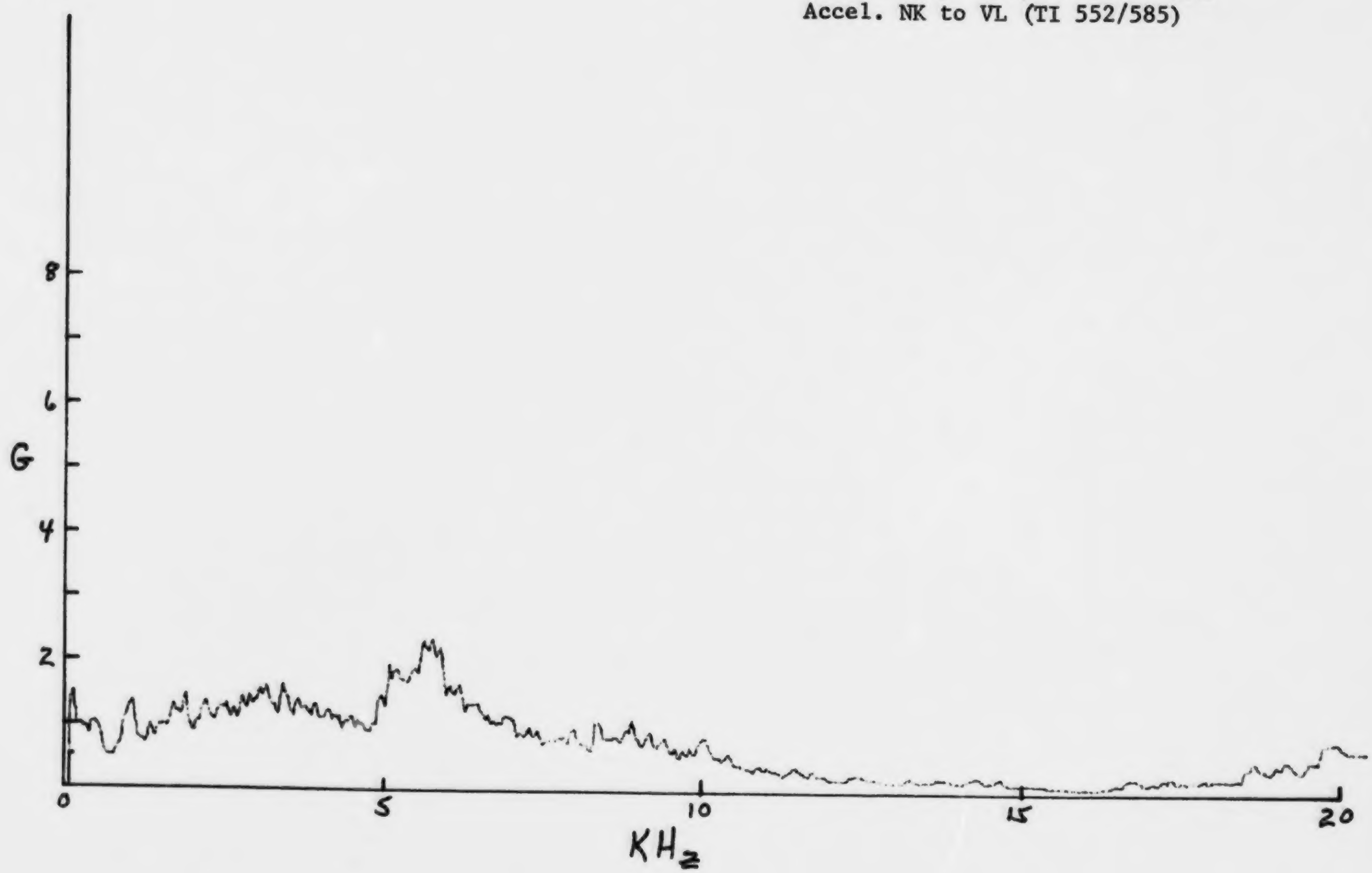


P14-5



P14 - 5   2.3 L, 4 cyl.
Rear Head, C-95, 30 to 60
MPH Accel. NK to VL (TI 552/585)

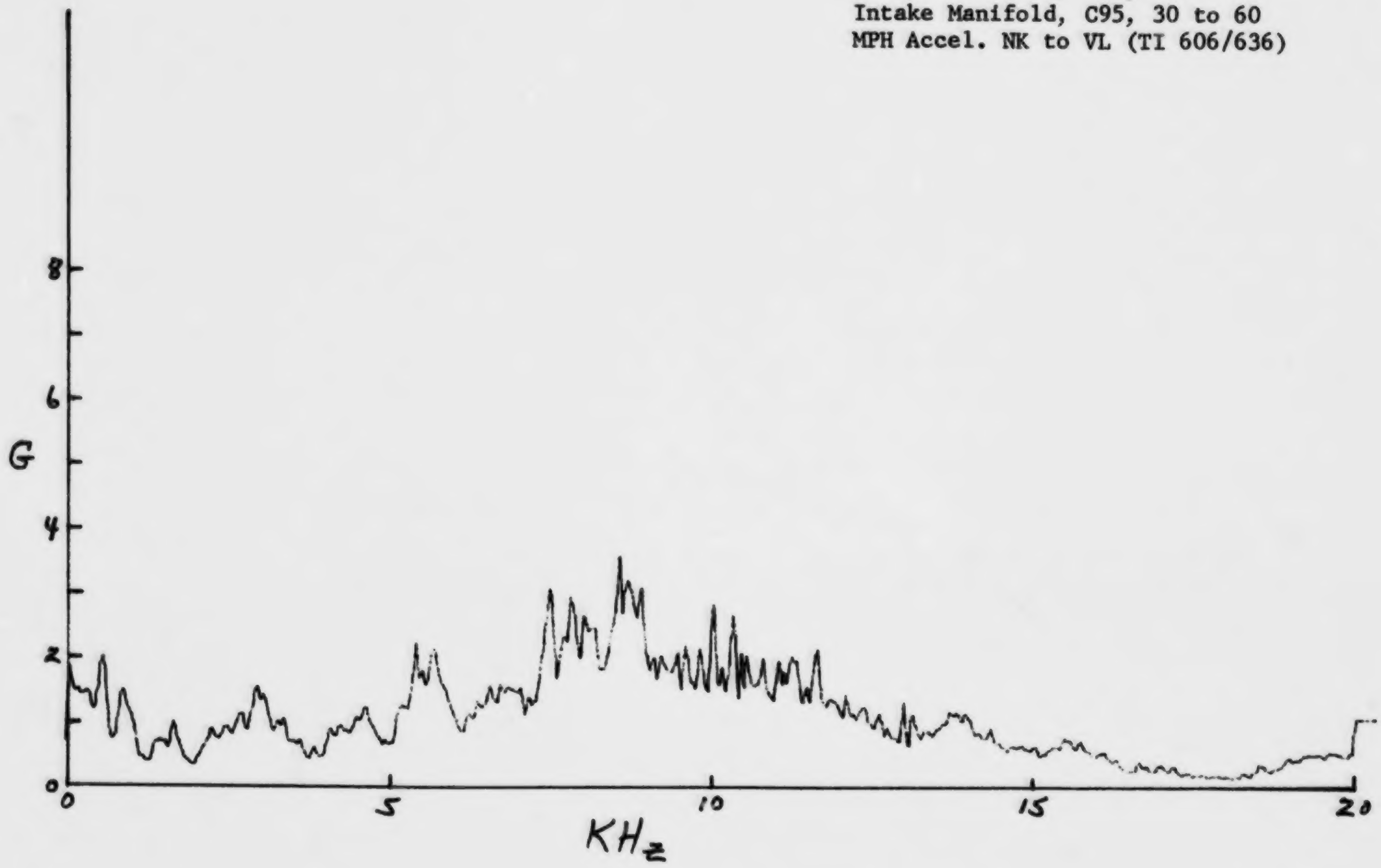
P14-6



P14 - 6   2.3 L, 4 cyl.
Rear Block, C-95, 30 to 60 MPH
Accel. NK to VL (TI 552/585)

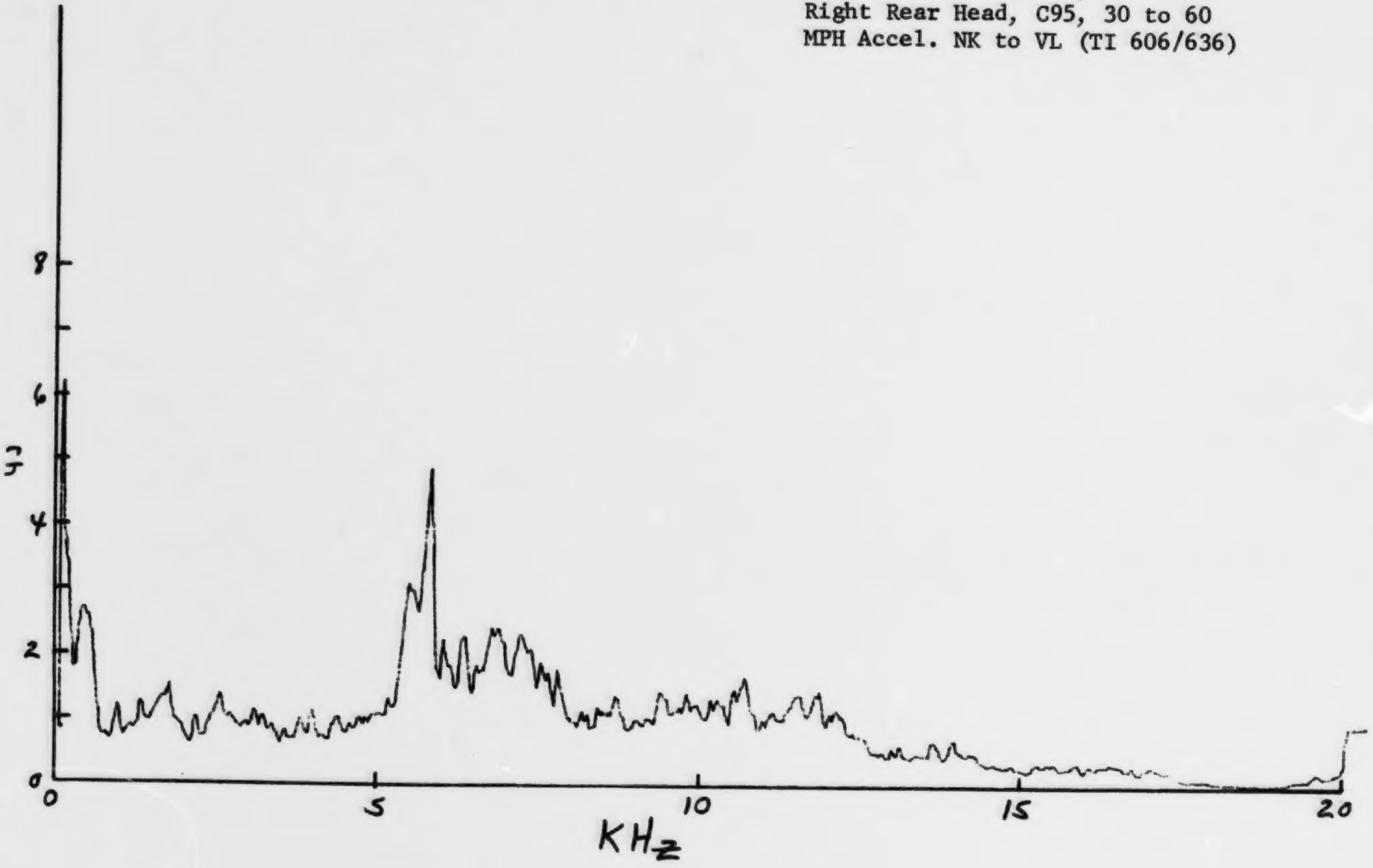
P15-5

P15 - 5   2.3 L, 4 cyl.
Intake Manifold, C95, 30 to 60
MPH Accel. NK to VL (TI 606/636)



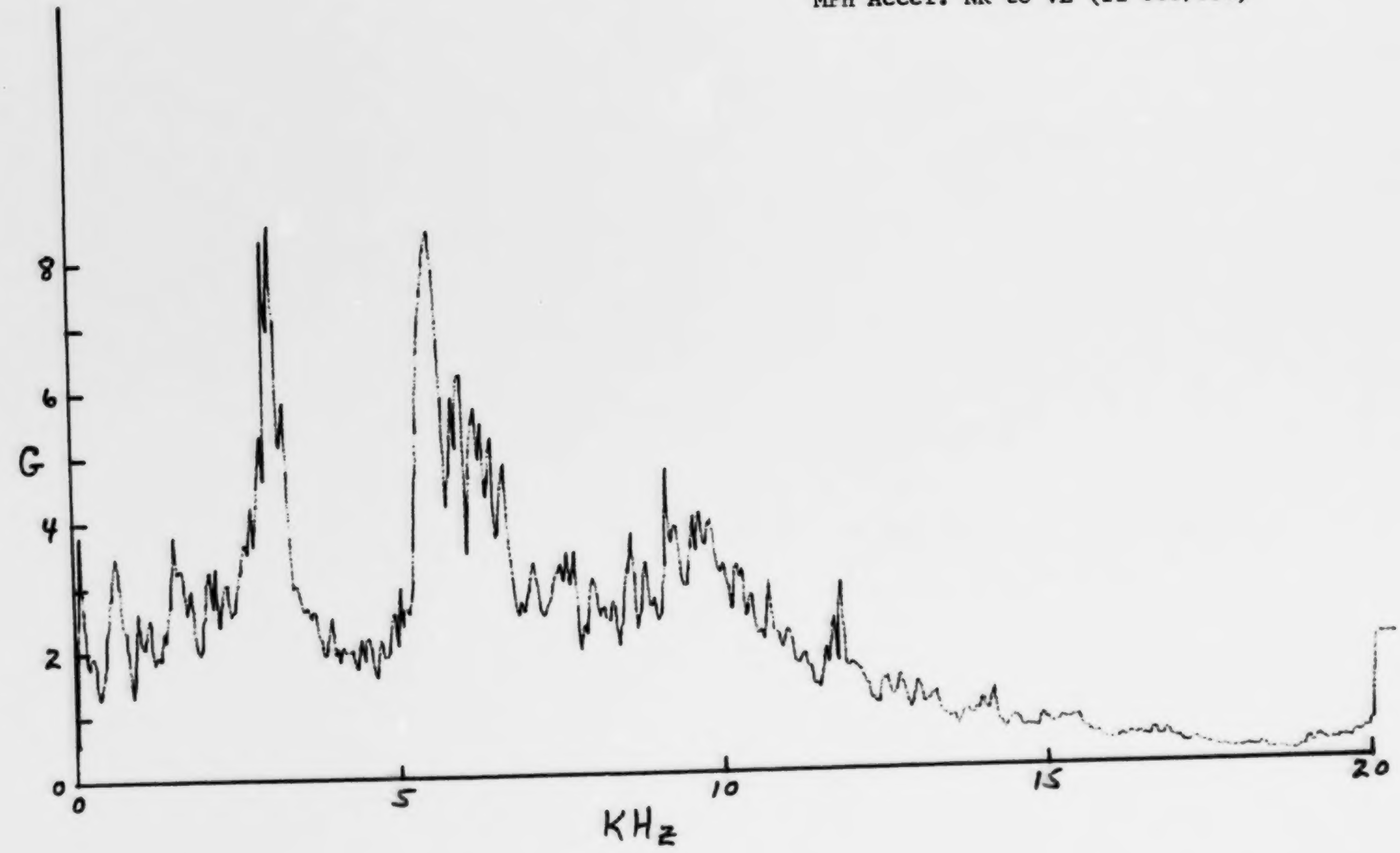
P15-6

P15 - 6   2.3 L, 4 cyl.
Right Rear Head, C95, 30 to 60
MPH Accel. NK to VL (TI 606/636)



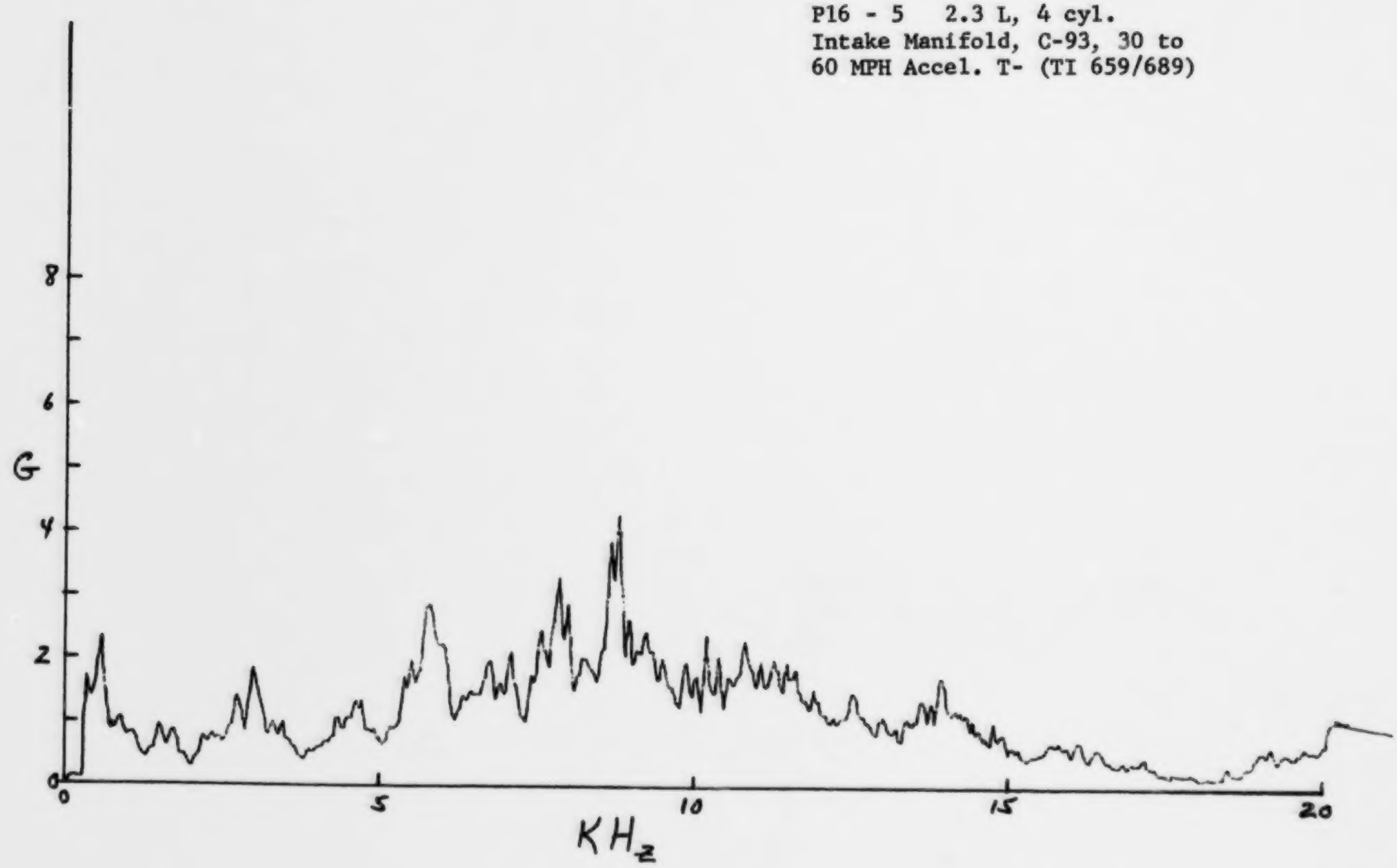
P15-7

P15 - 7   2.3 L, 4 cyl.
Right Front Block, C95, 30 to 60
MPH Accel. NK to VL (TI 606/636)

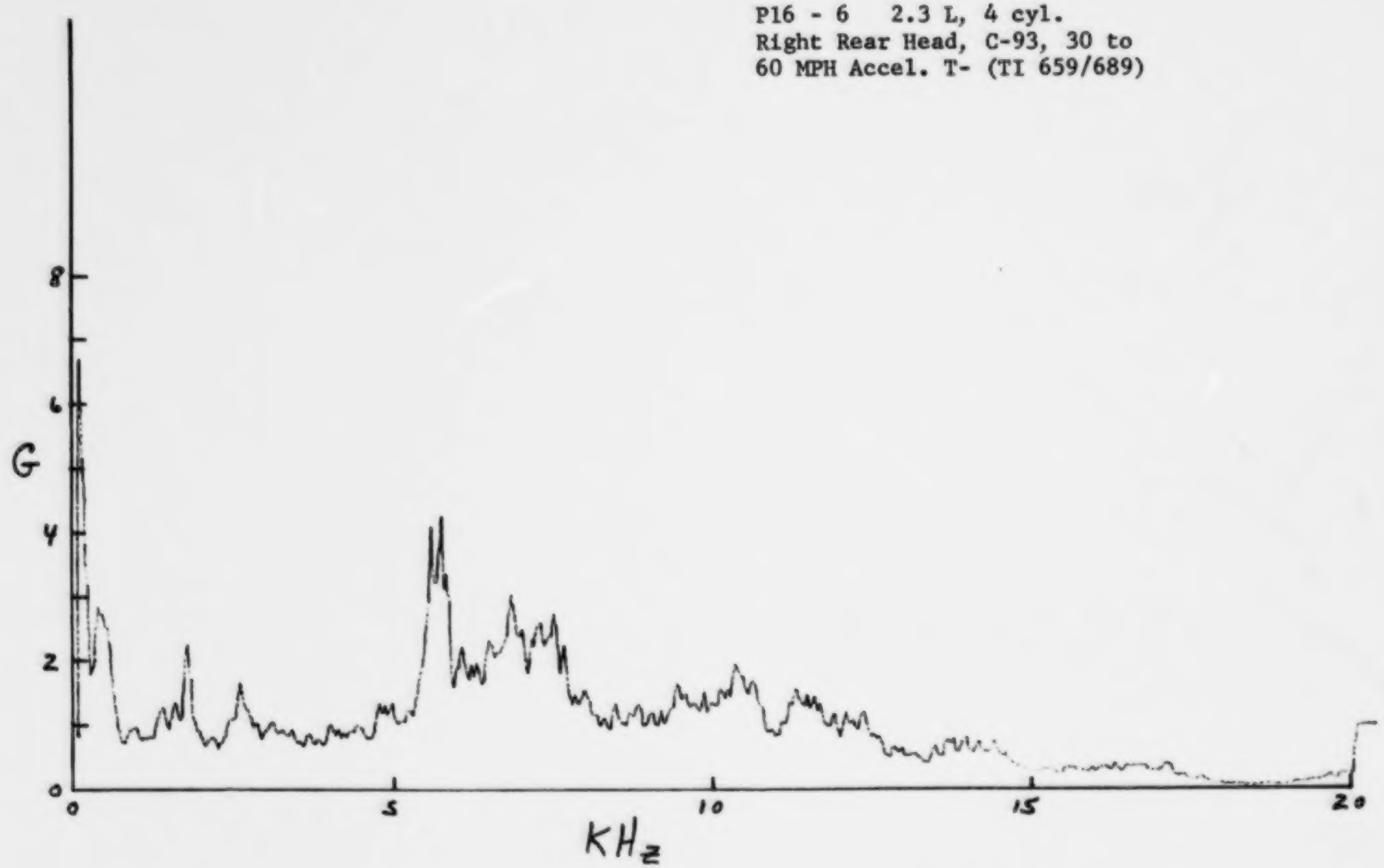


P16-5

P16 - 5   2.3 L, 4 cyl.
Intake Manifold, C-93, 30 to
60 MPH Accel. T- (TI 659/689)

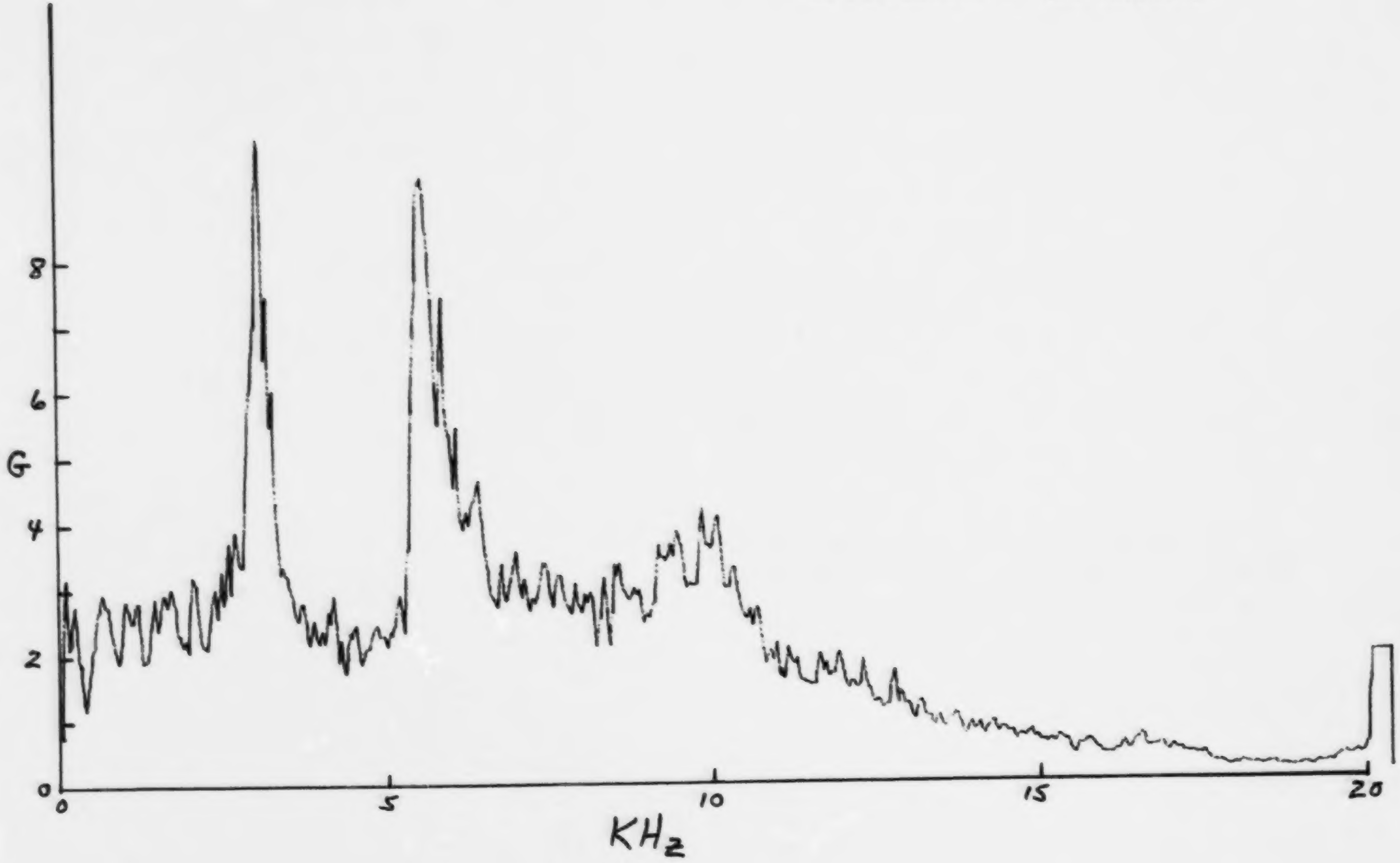


P16-6



P16 - 6   2.3 L, 4 cyl.
Right Rear Head, C-93, 30 to
60 MPH Accel. T- (TI 659/689)

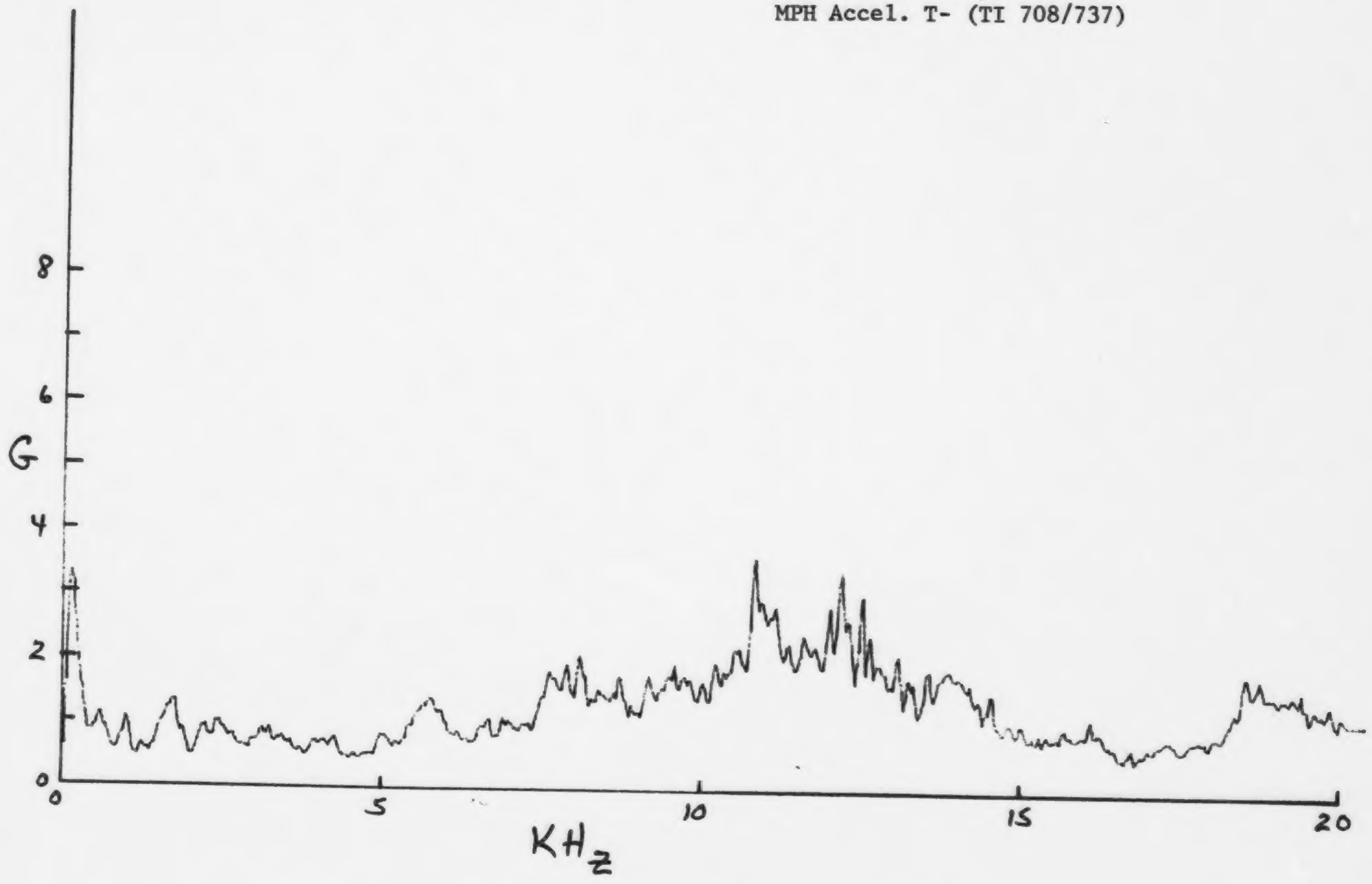
P16-7



P16 - 7 2.3 L, 4 cyl.
Right Front Block, C-93, 30 to
60 MPH Accel. T- (TI 659/689)

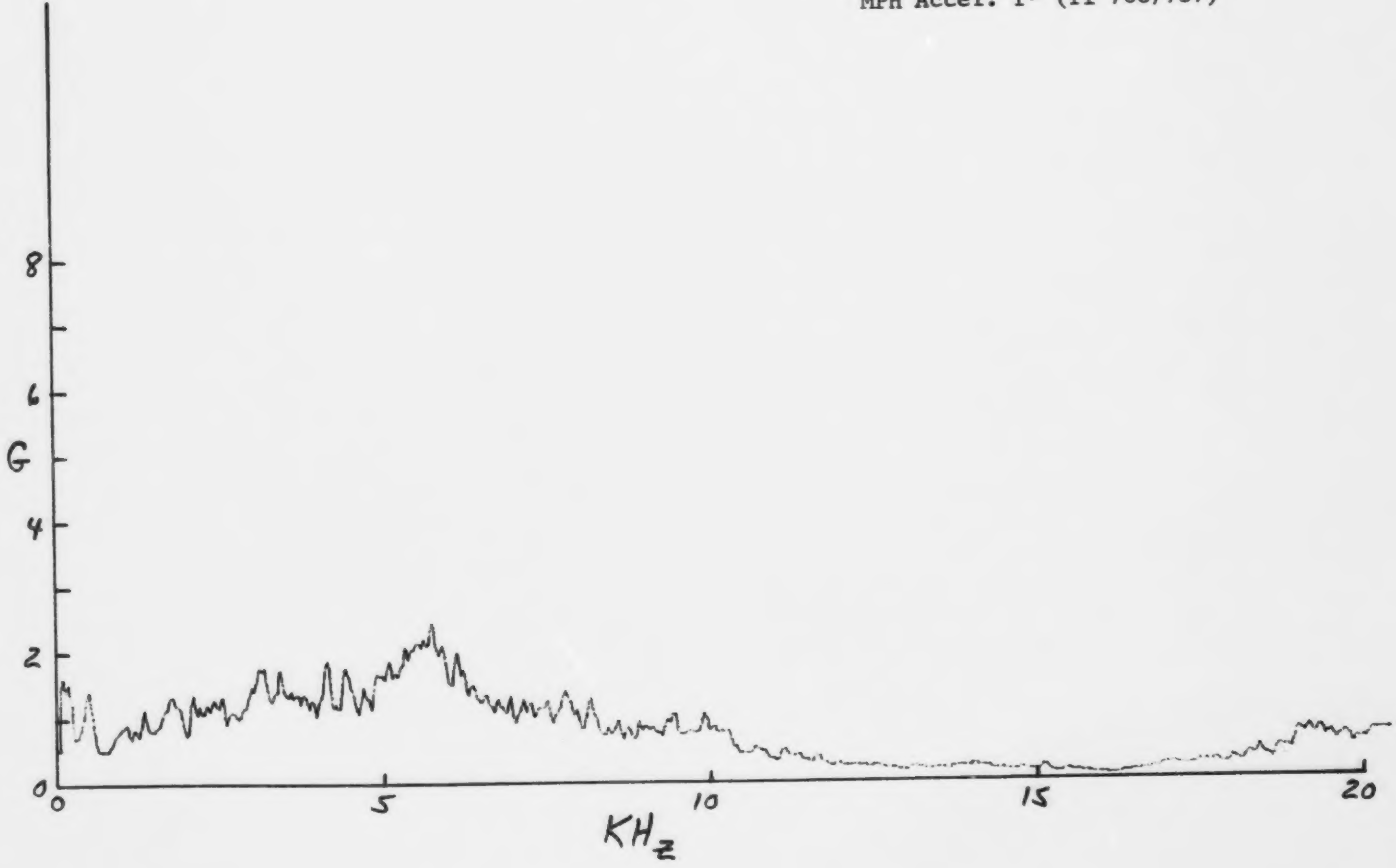
P17-5

P17 - 5   2.3 L, 4 cyl.
Rear Head, C-93, 30 to 60
MPH Accel. T- (TI 708/737)



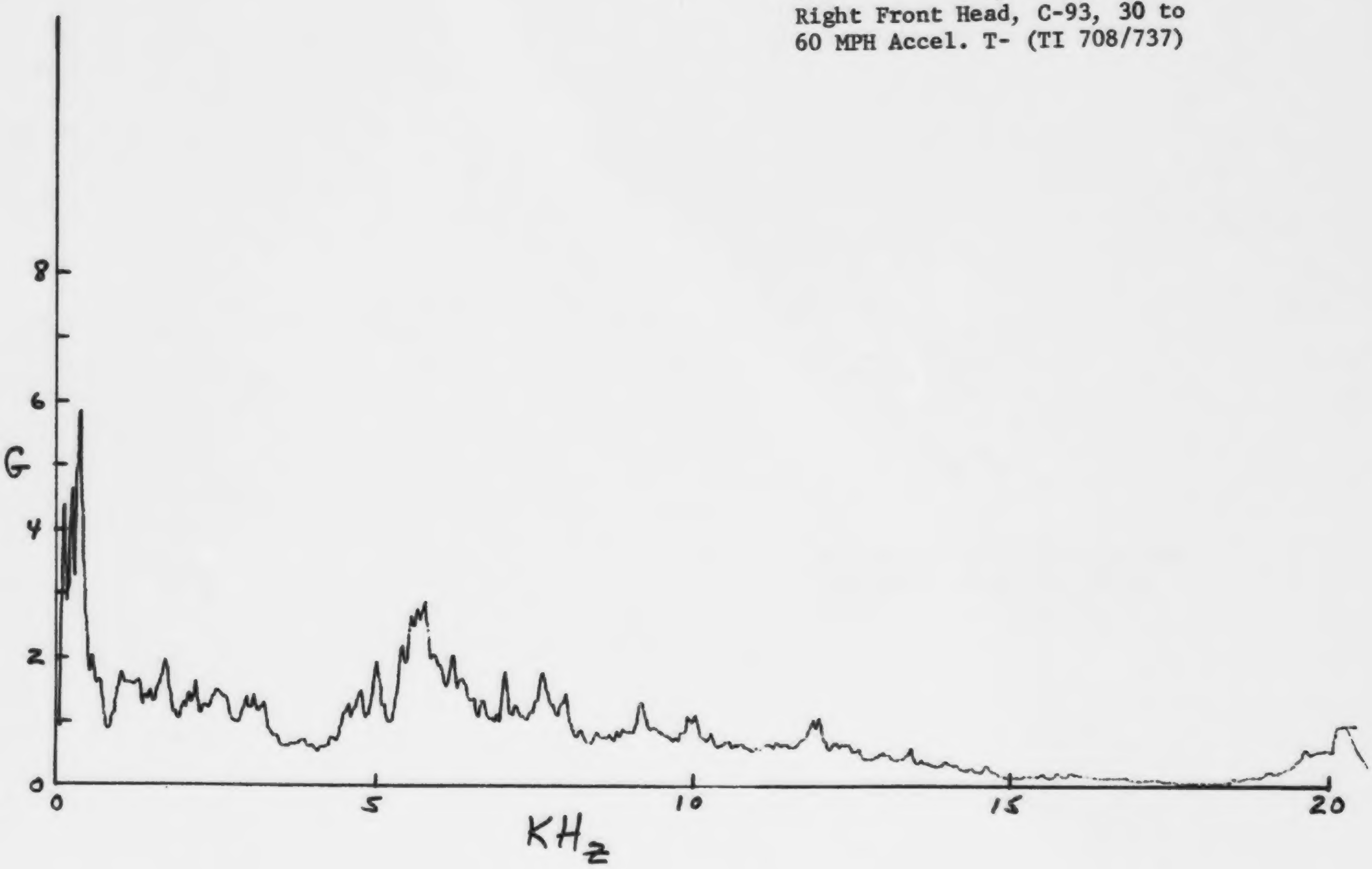
P17-6

P17 - 6   2.3 L, 4 cyl.
Rear Block, C-93, 30 to 60
MPH Accel. T- (TI 708/737)

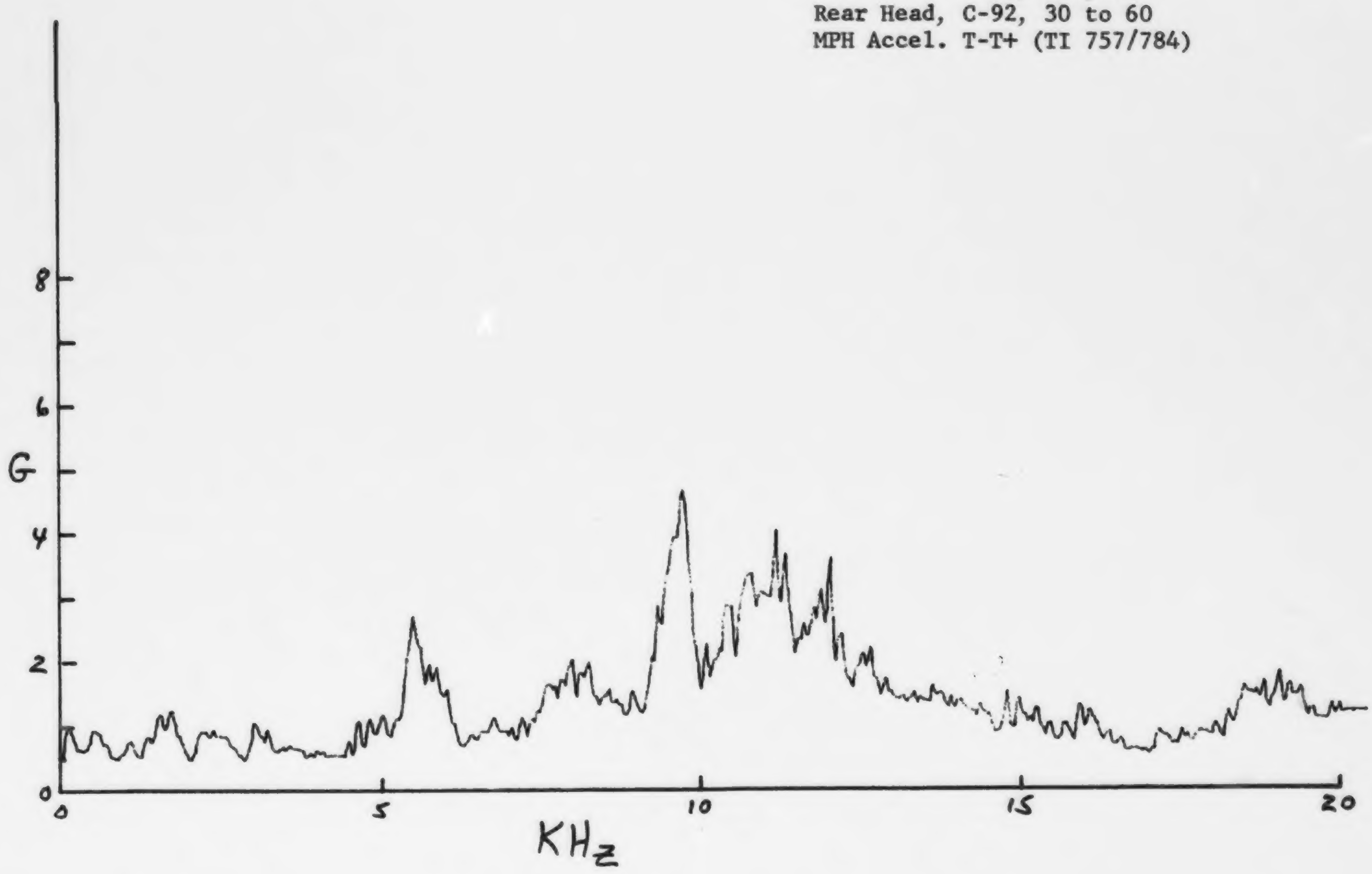


P17-7

P17 - 7   2.3 L, 4 cyl.
Right Front Head, C-93, 30 to
60 MPH Accel. T- (TI 708/737)



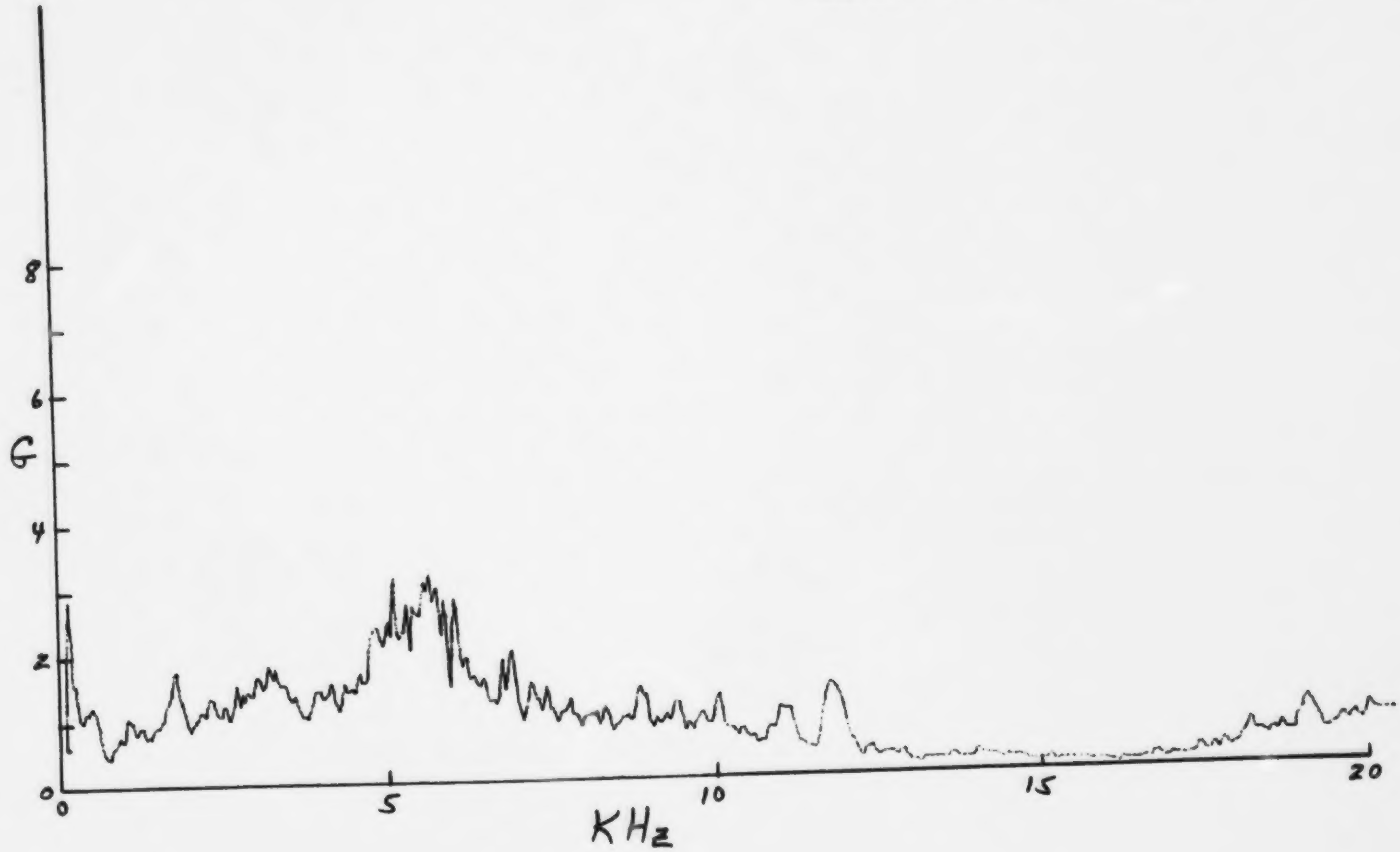
P18-5



P18 - 5   2.3 L, 4 cyl.
Rear Head, C-92, 30 to 60
MPH Accel. T-T+ (TI 757/784)

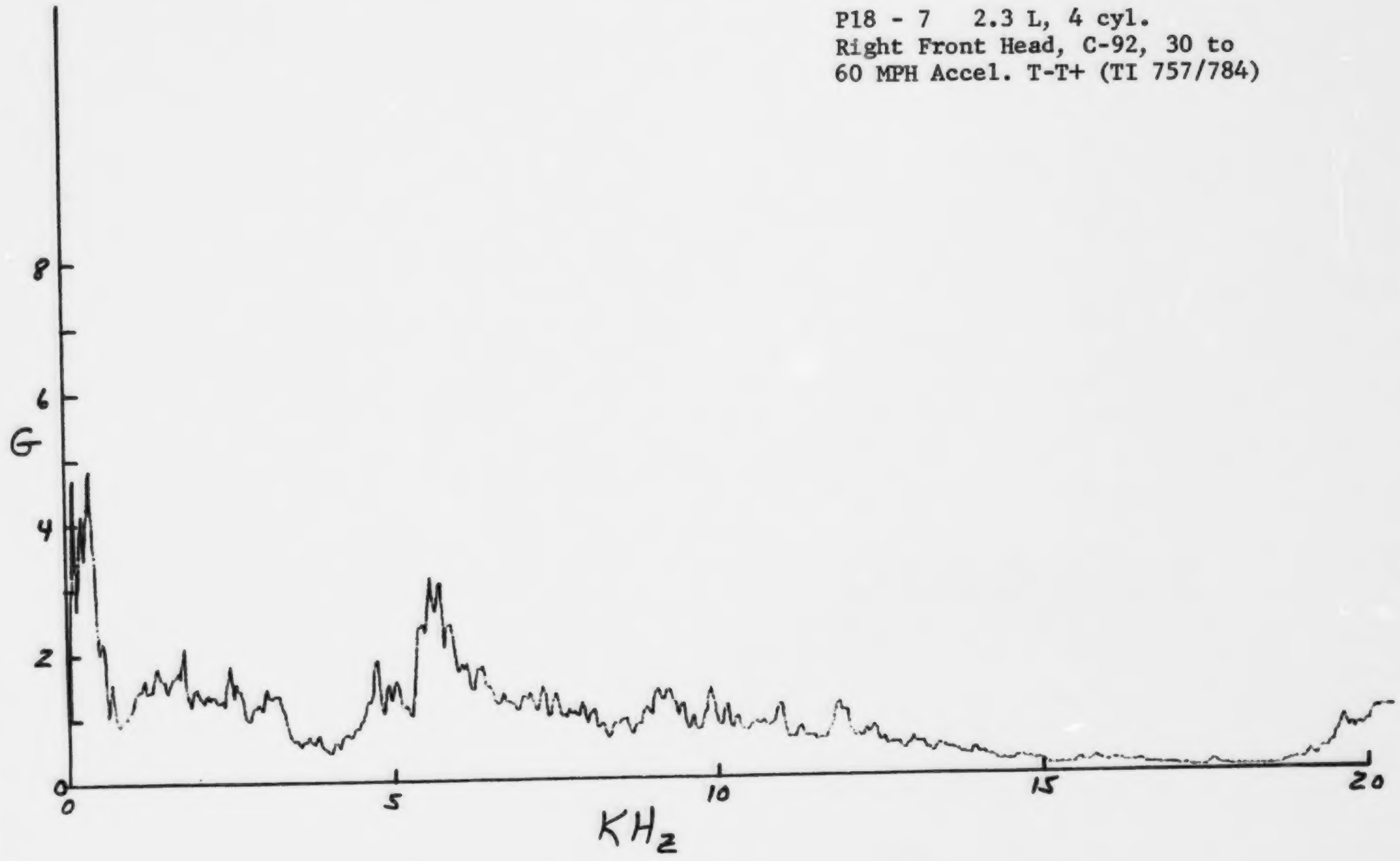
P18-6

P18 - 6   2.3 L, 4 cyl.
Rear Block, C-92, 30 to 60
MPH Accel. T-T+ (TI 757/784)

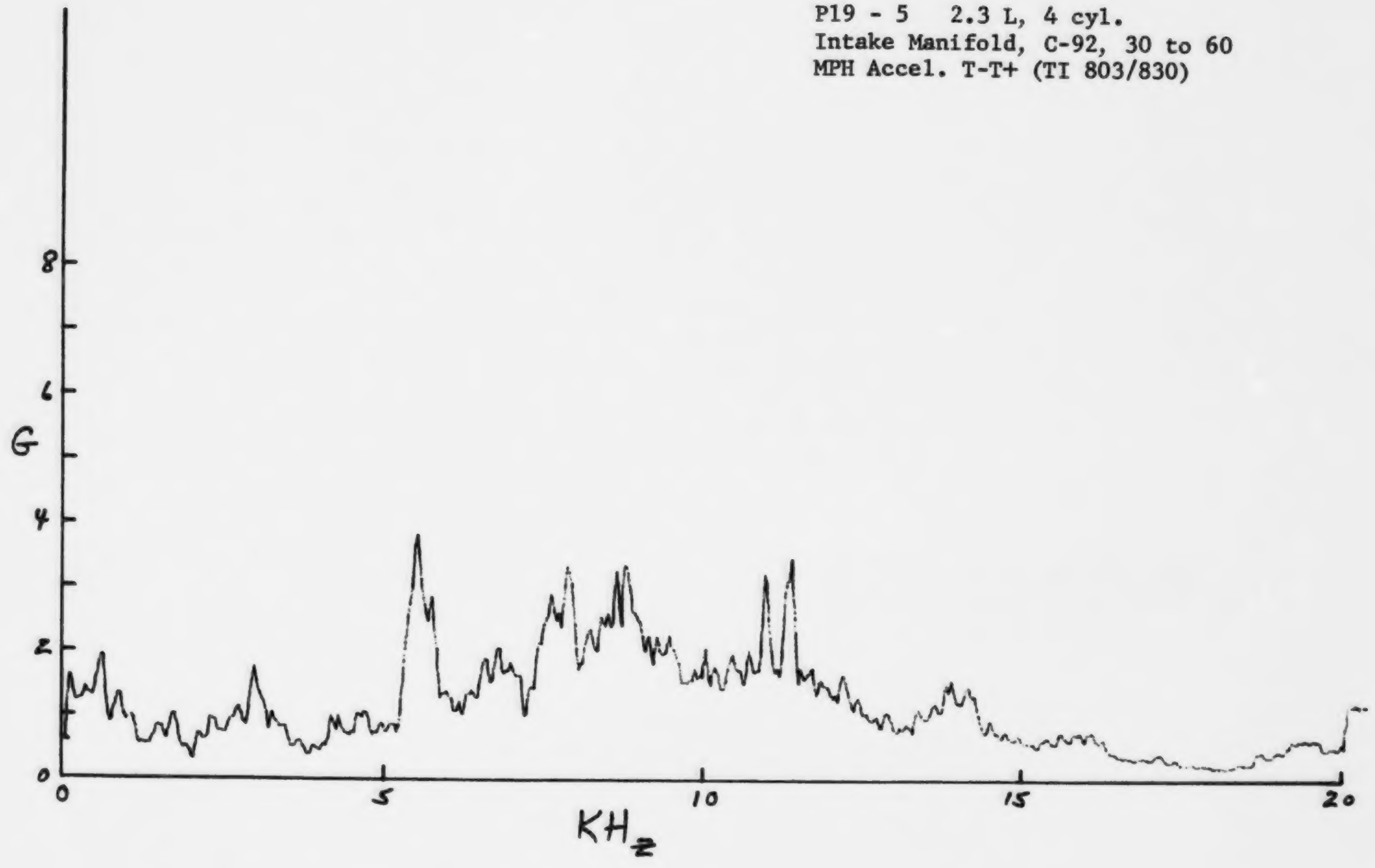


P18-7

P18 - 7   2.3 L, 4 cyl.
Right Front Head, C-92, 30 to
60 MPH Accel. T-T+ (TI 757/784)

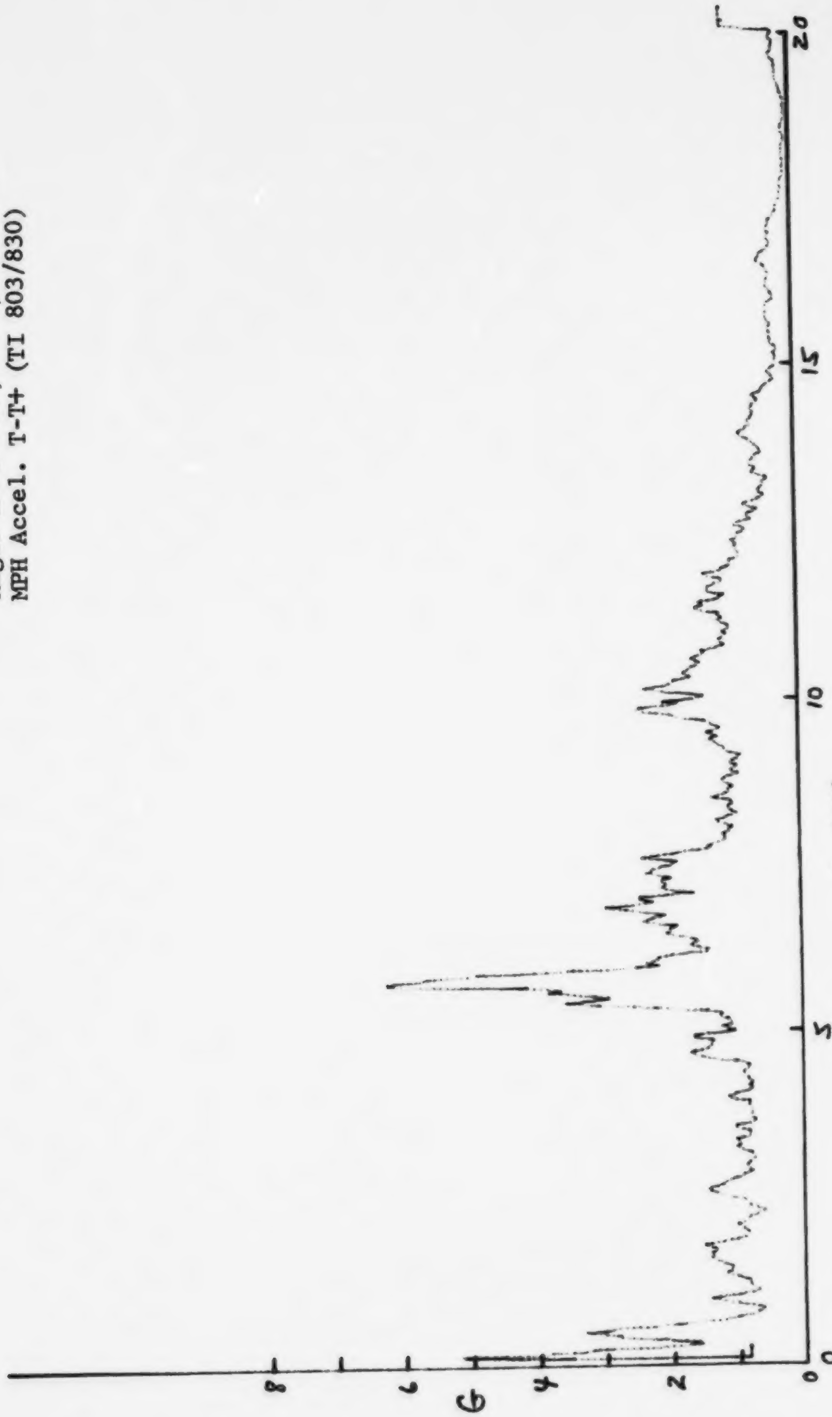


P19-5



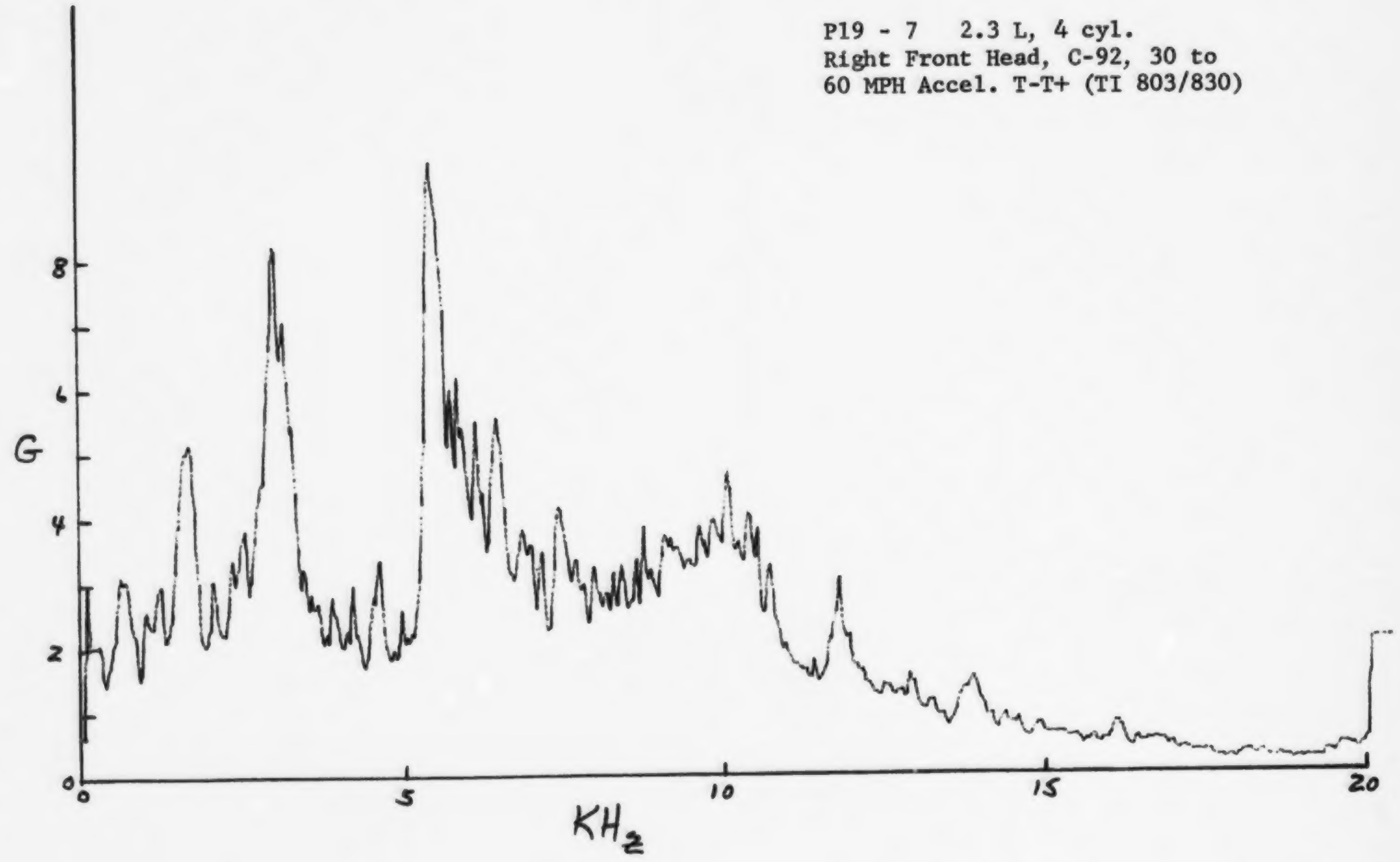
P19 - 5   2.3 L, 4 cyl.
Intake Manifold, C-92, 30 to 60
MPH Accel. T-T+ (TI 803/830)

P19-6



P19 - 6 2.3 L, 4 cyl.
Right Rear Head, C-92, 30 to 60
MPH Accel. T-T+ (TI 803/830)

P19-7

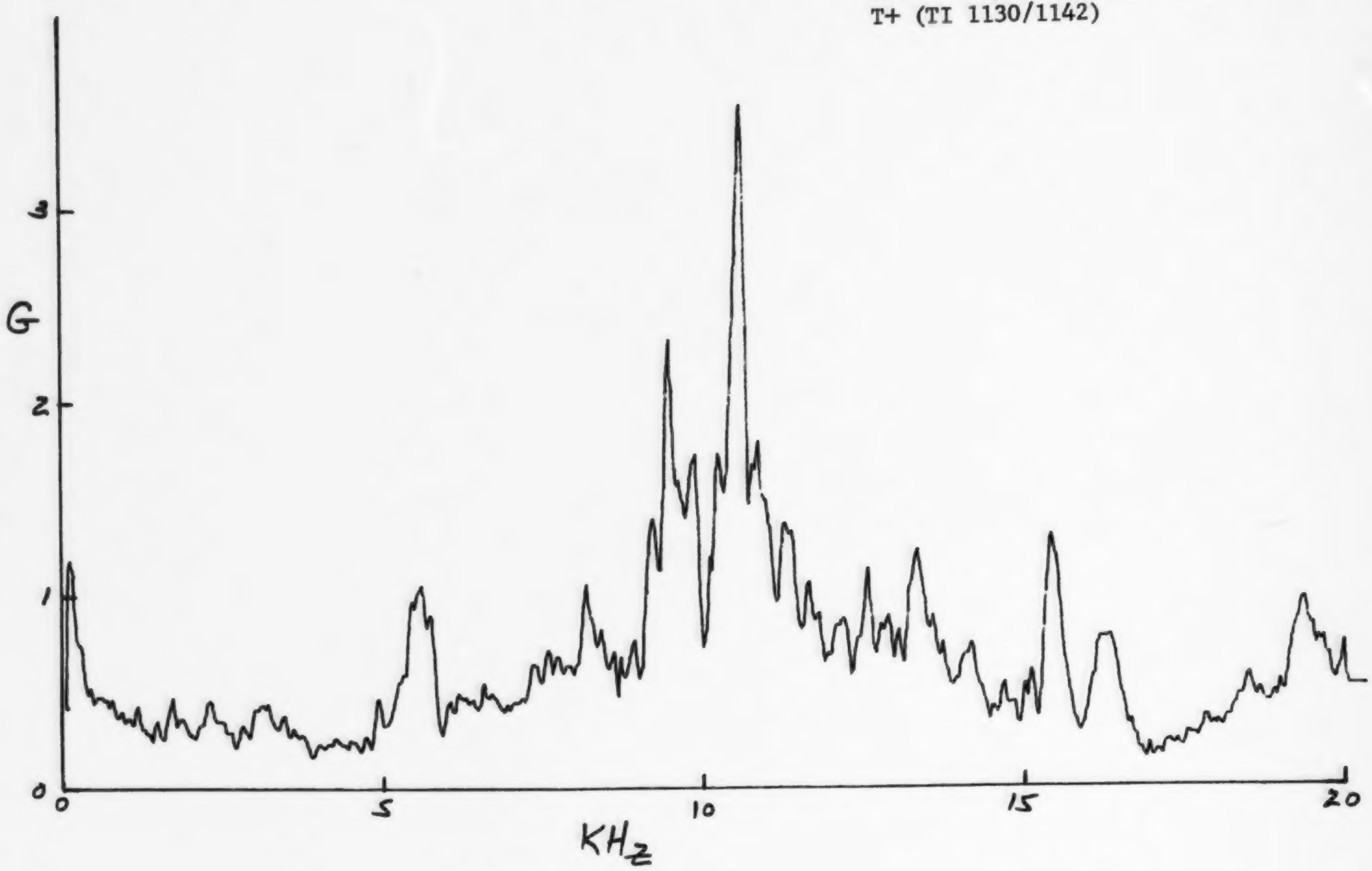


P19 - 7   2.3 L, 4 cyl.
Right Front Head, C-92, 30 to
60 MPH Accel. T-T+ (TI 803/830)

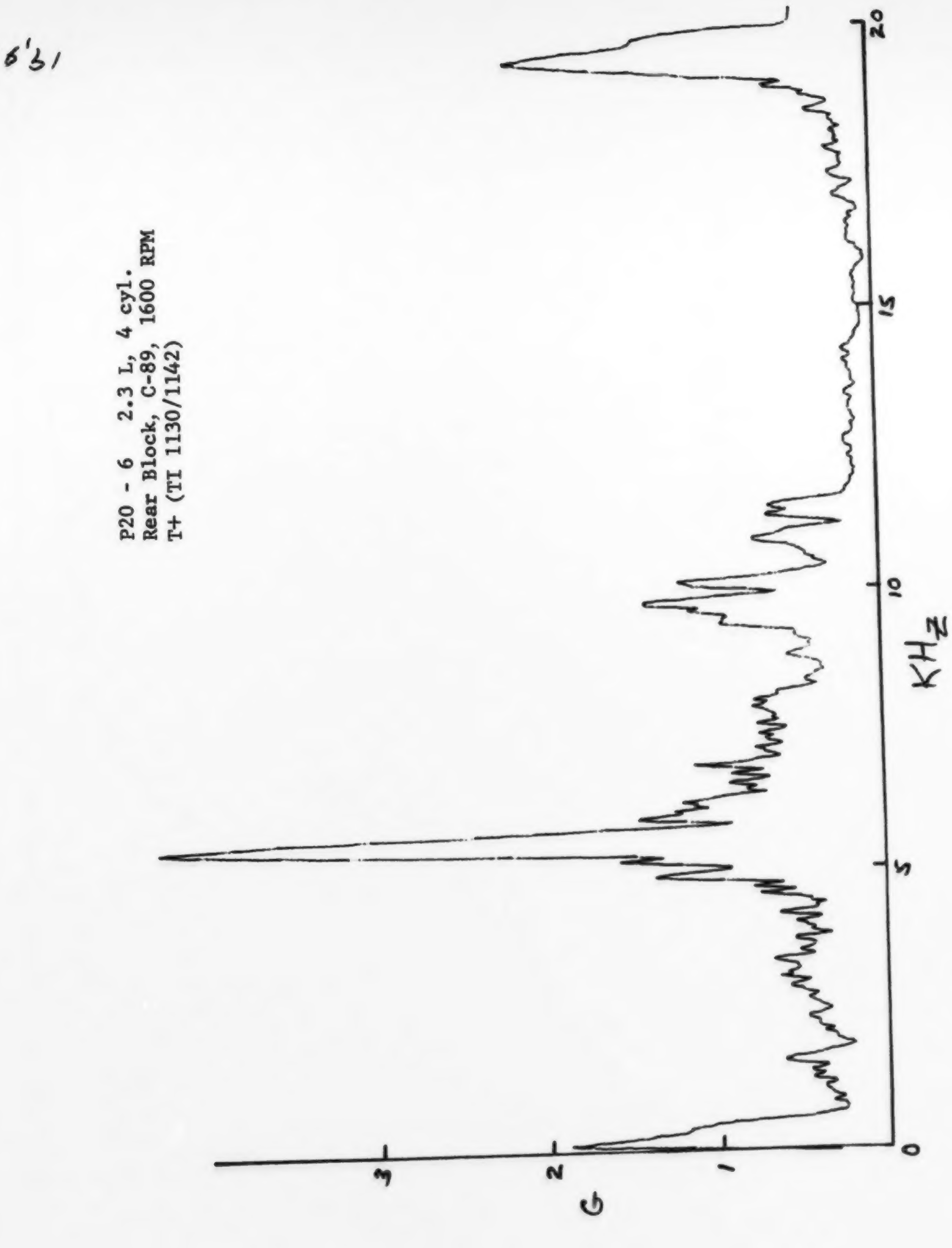
P20-5

10,600

P20 - 5   2.3 L, 4 cyl.
Rear Head, C-89, 1600 RPM
T+ (TI 1130/1142)



P20-6

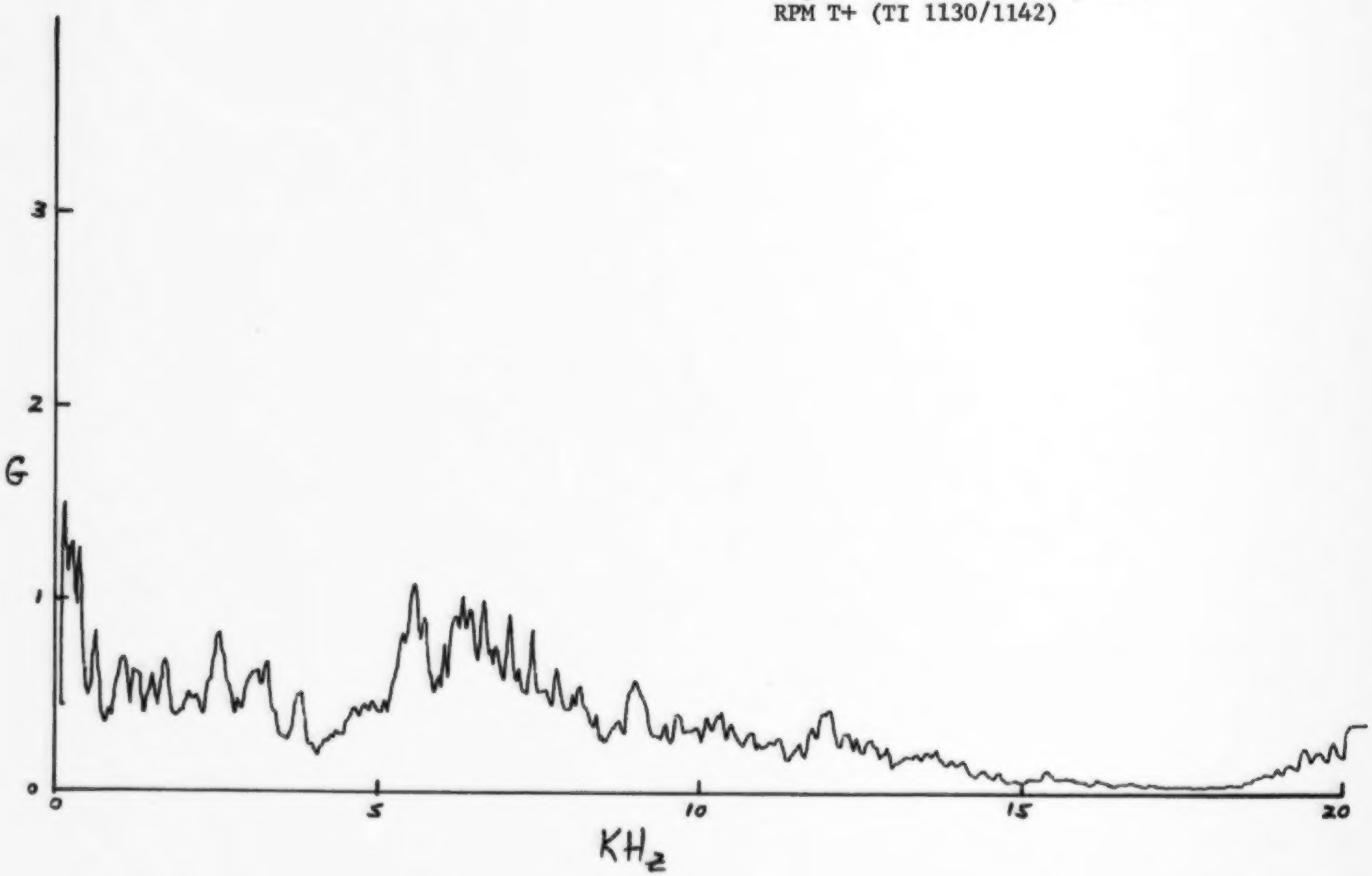


P20 - 6 2.3 L, 4 cyl.
Rear Block, C-89, 1600 RPM
T+ (TI 1130/1142)

17,940

5520

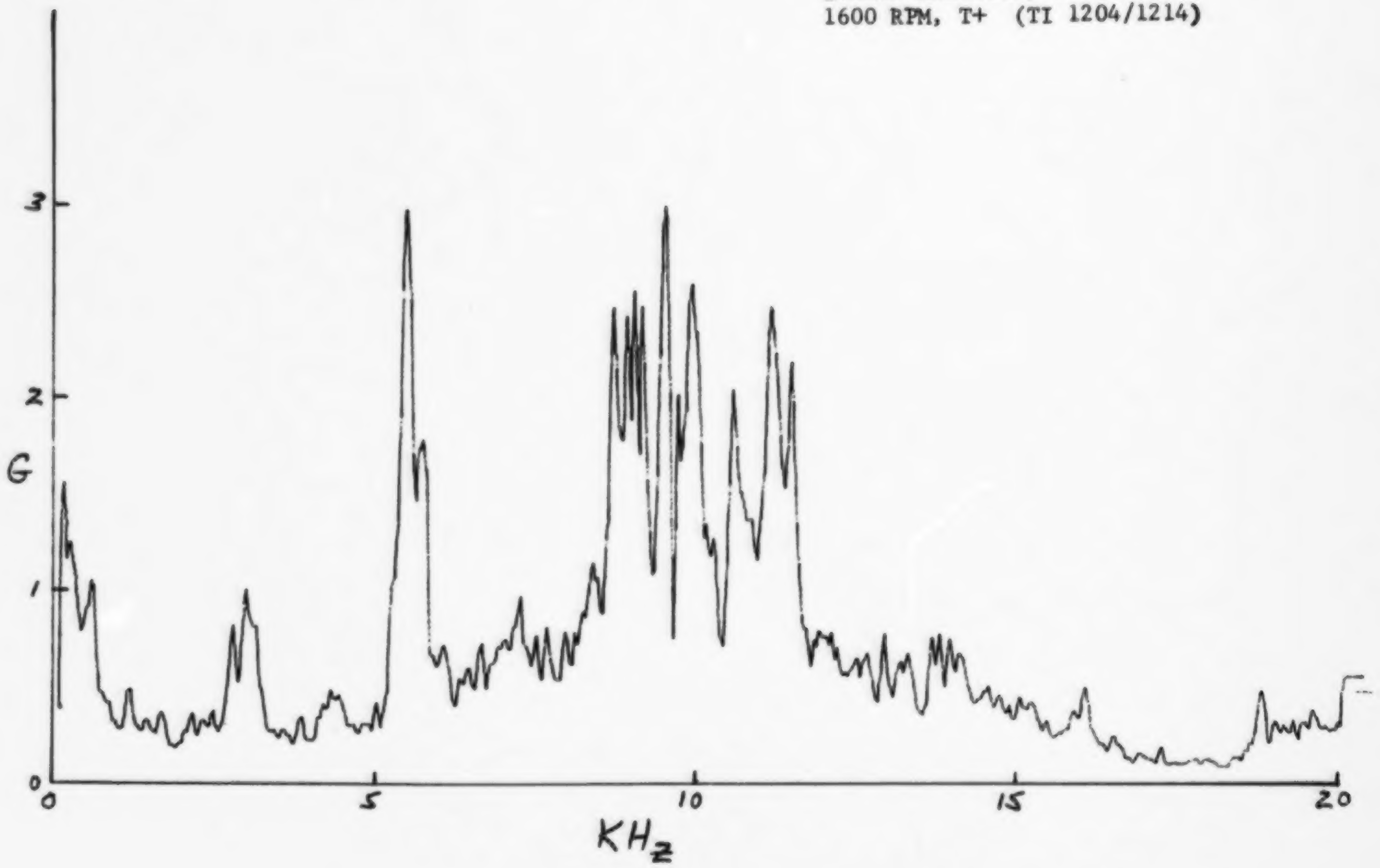
P20-7



P20 - 7   2.3 L, 4 cyl.
Right Front Head, C-89, 1600
RPM T+ (TI 1130/1142)

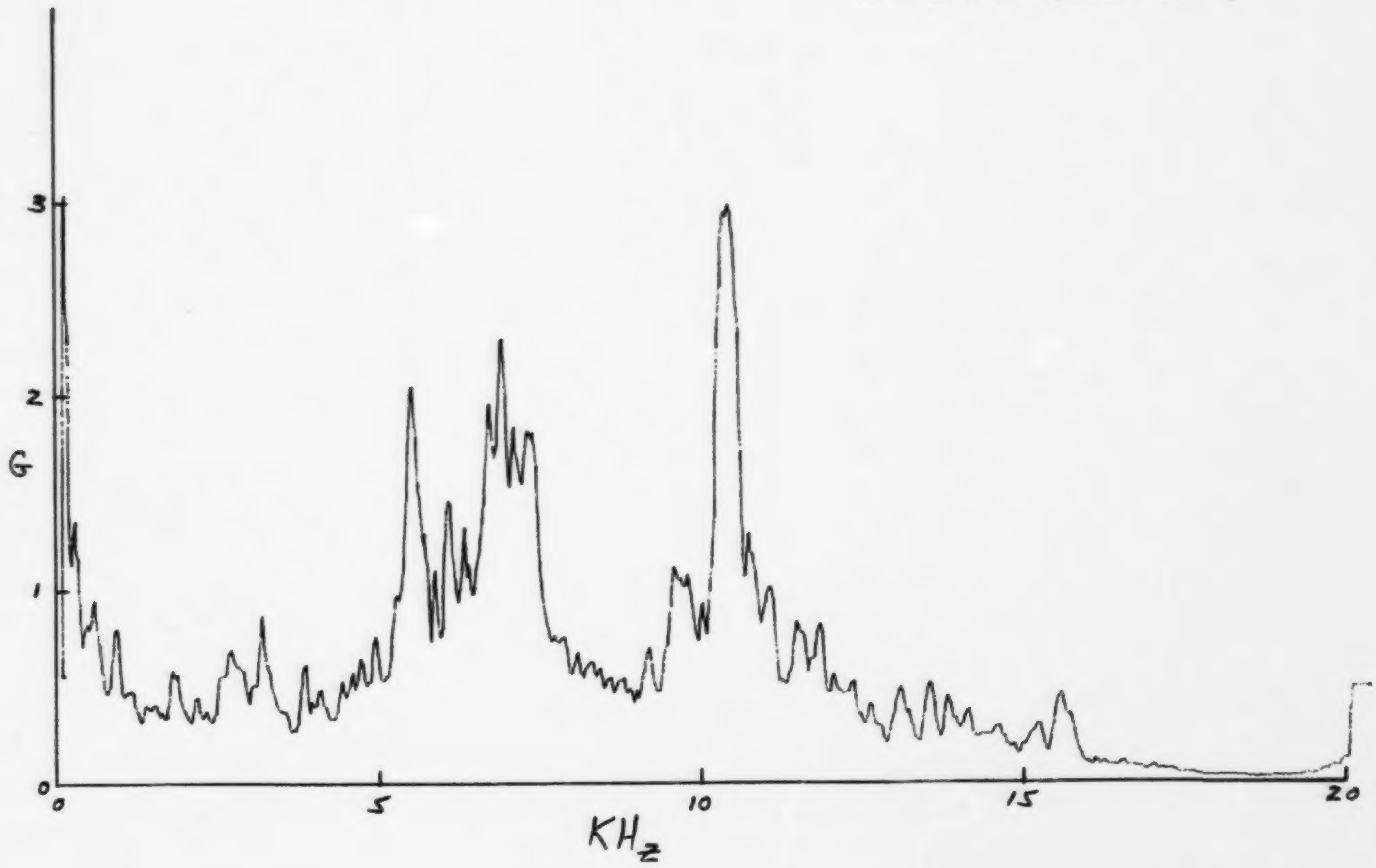
P21-5

P21 - 5   2.3 L, 4 cyl.
Intake Manifold, C-89
1600 RPM, T+ (TI 1204/1214)



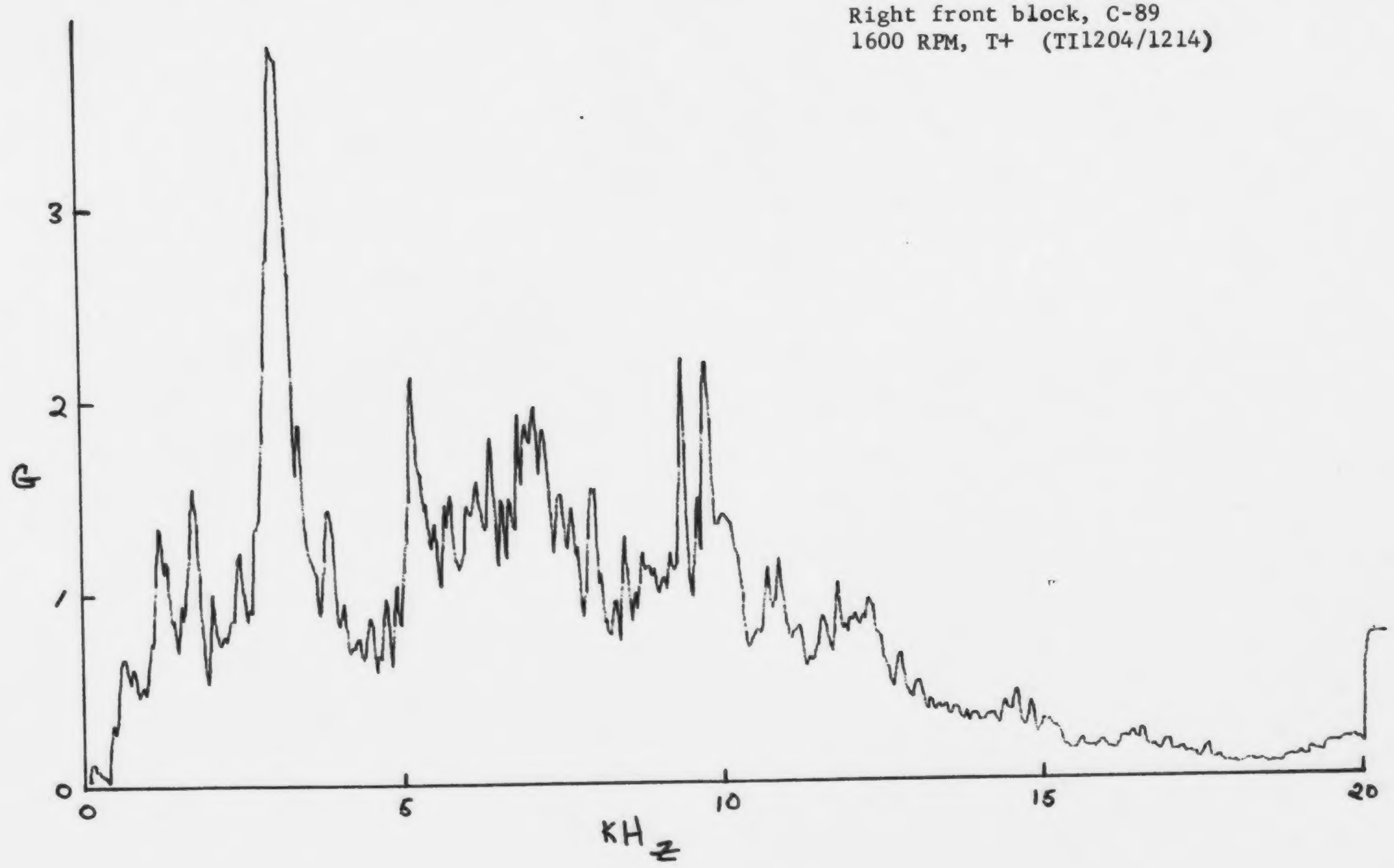
P21-6

P21 - 6 2.3 L, 4 cyl.
Right rear head, C-89
1600 RPM, T+ (TI 1204/1214)



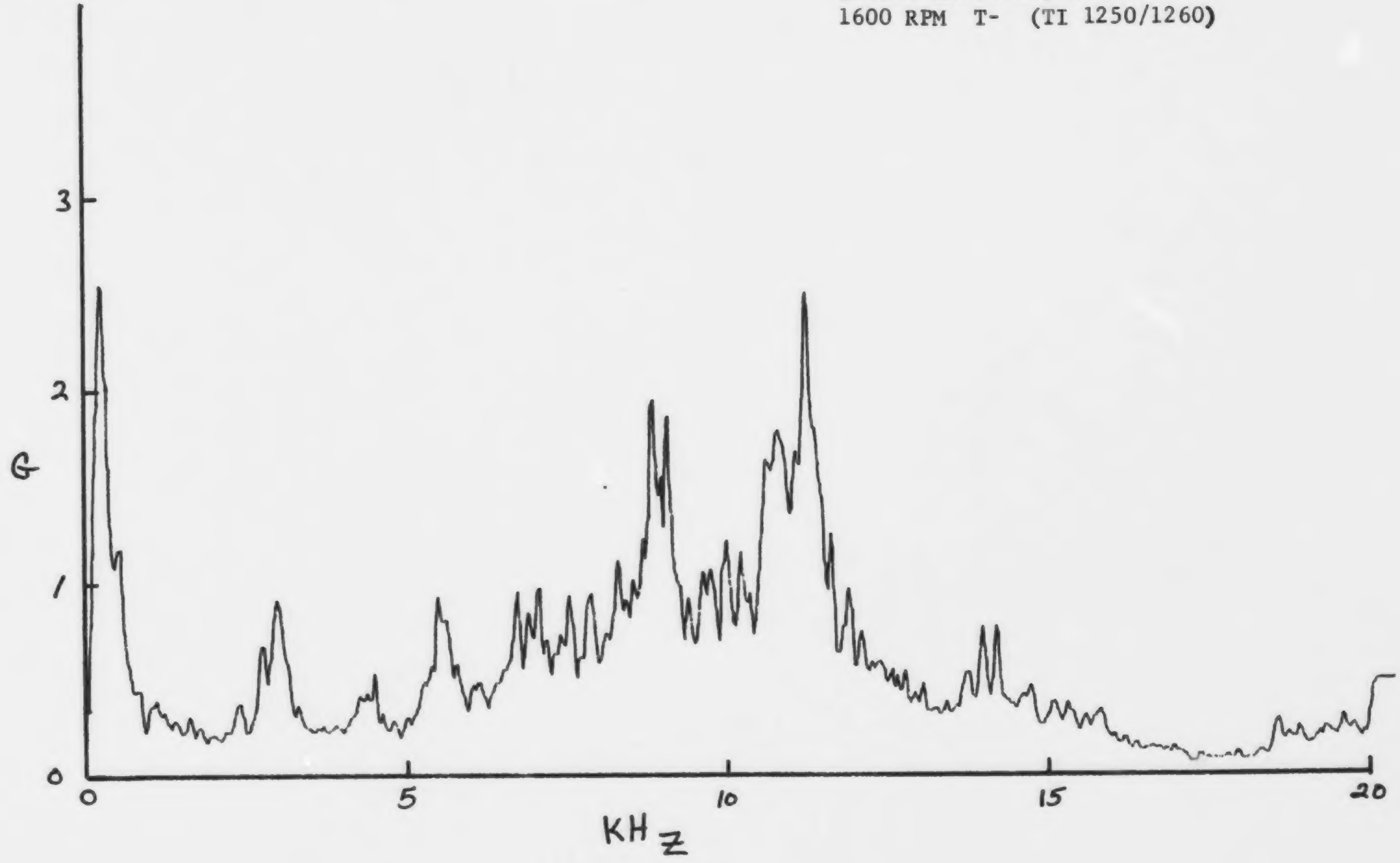
P21-7

P21 - 7 2.3 L, 4cyl.
Right front block, C-89
1600 RPM, T+ (TI1204/1214)

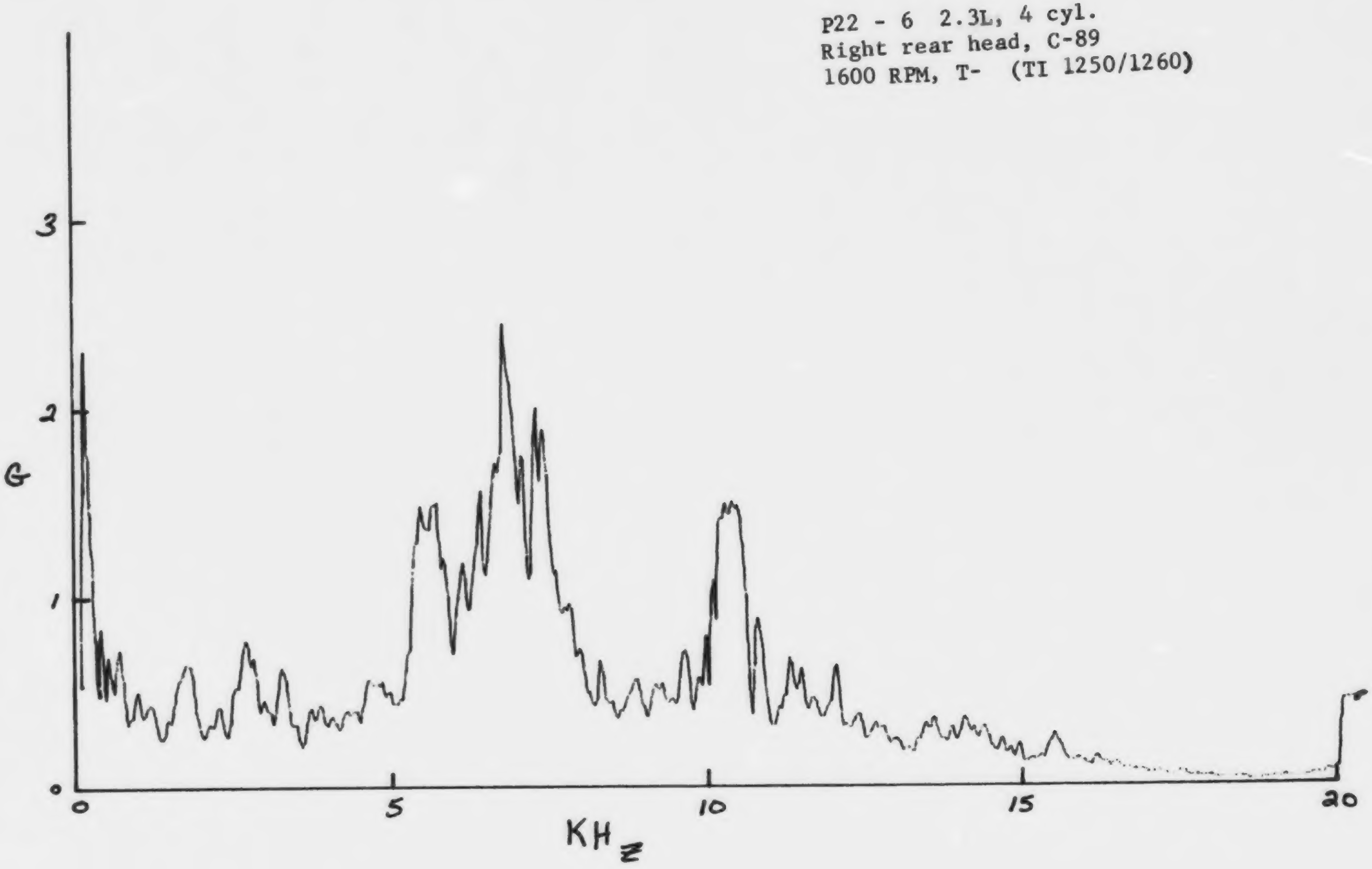


P22-5

P22 - 5 2.3 L, 4 cyl.
Intake Manifold, C-89
1600 RPM T- (TI 1250/1260)

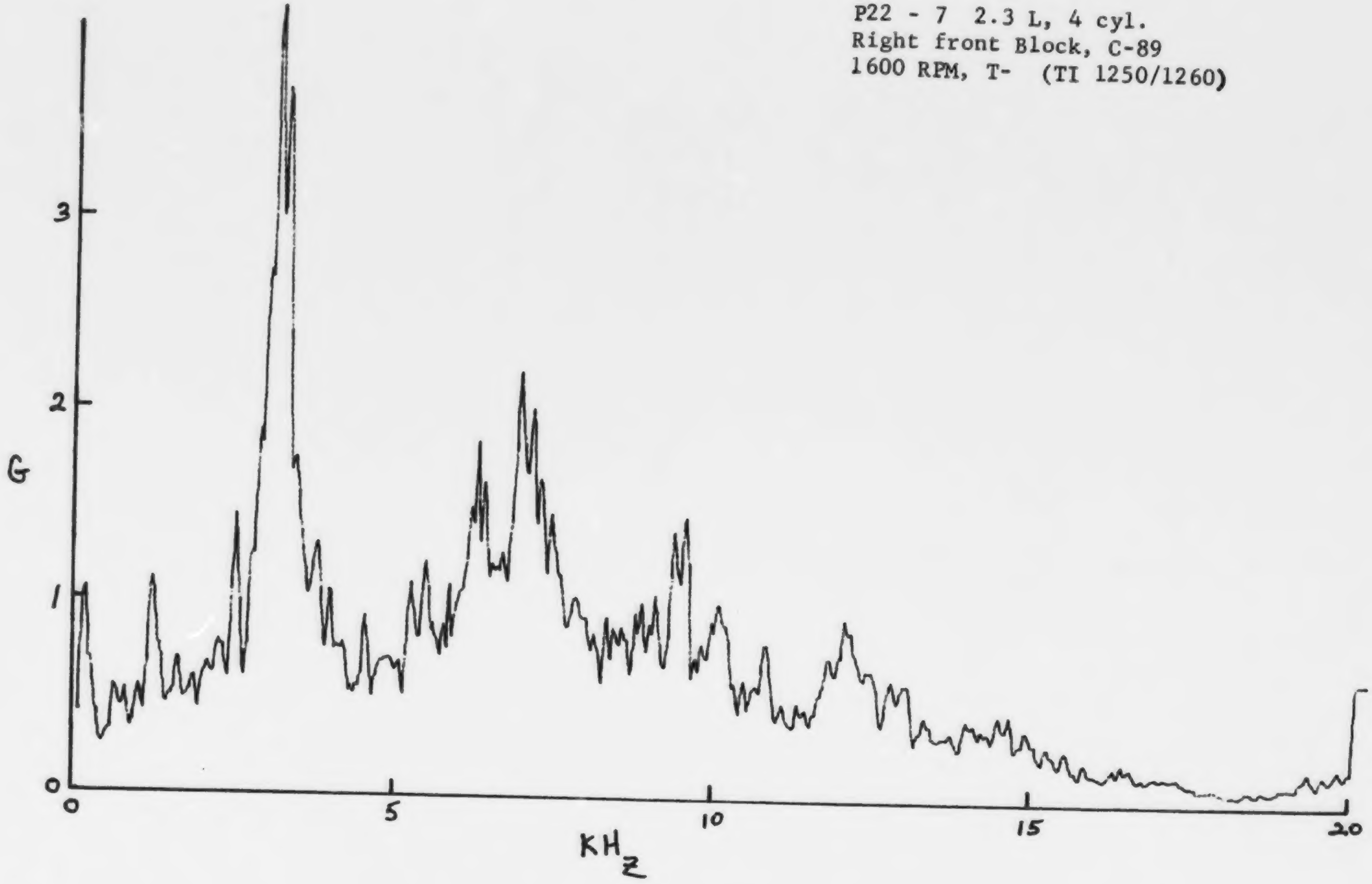


P22 - 6



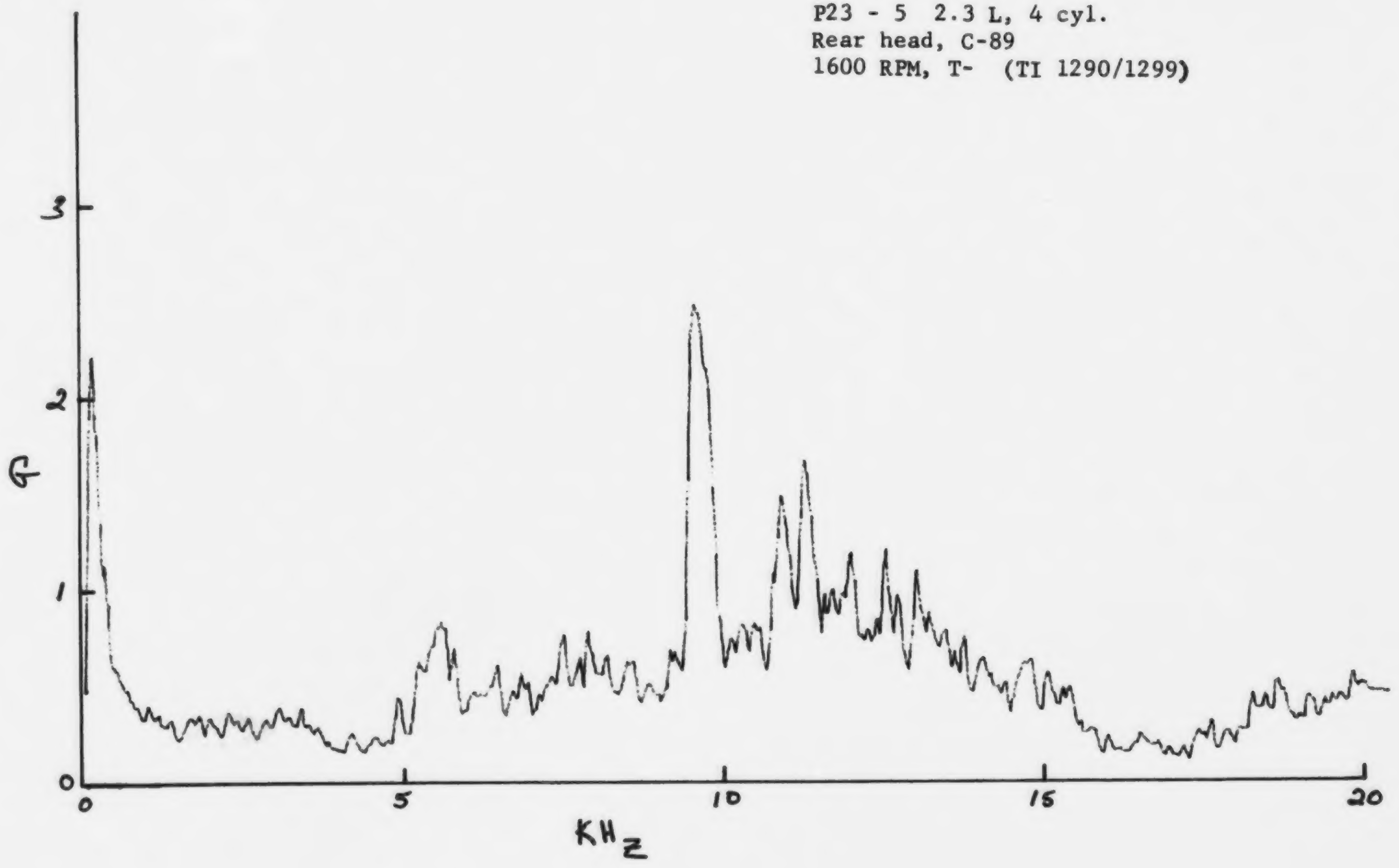
P22 - 6 2.3L, 4 cyl.
Right rear head, C-89
1600 RPM, T- (TI 1250/1260)

P22-7

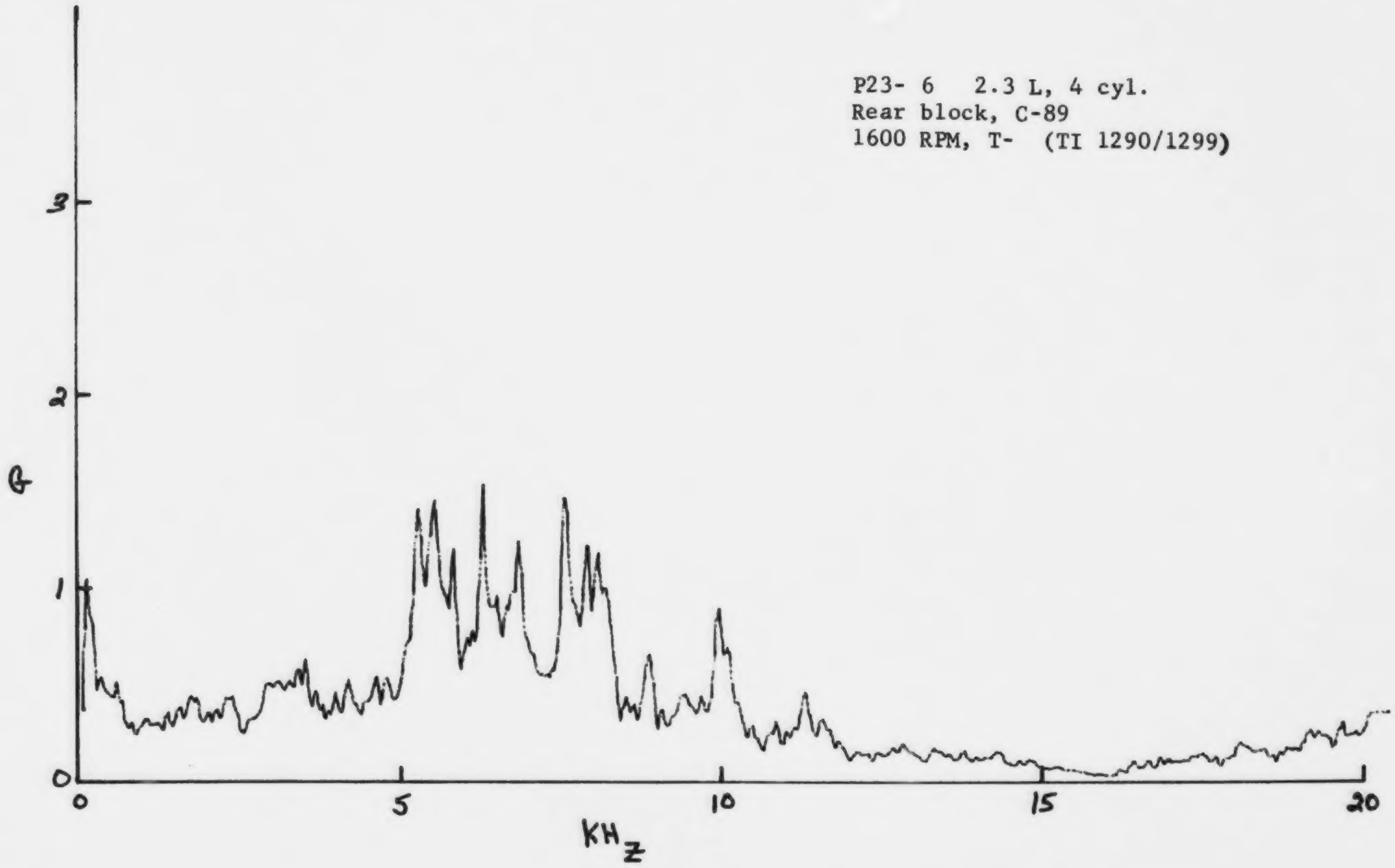


P22 - 7 2.3 L, 4 cyl.
Right front Block, C-89
1600 RPM, T- (TI 1250/1260)

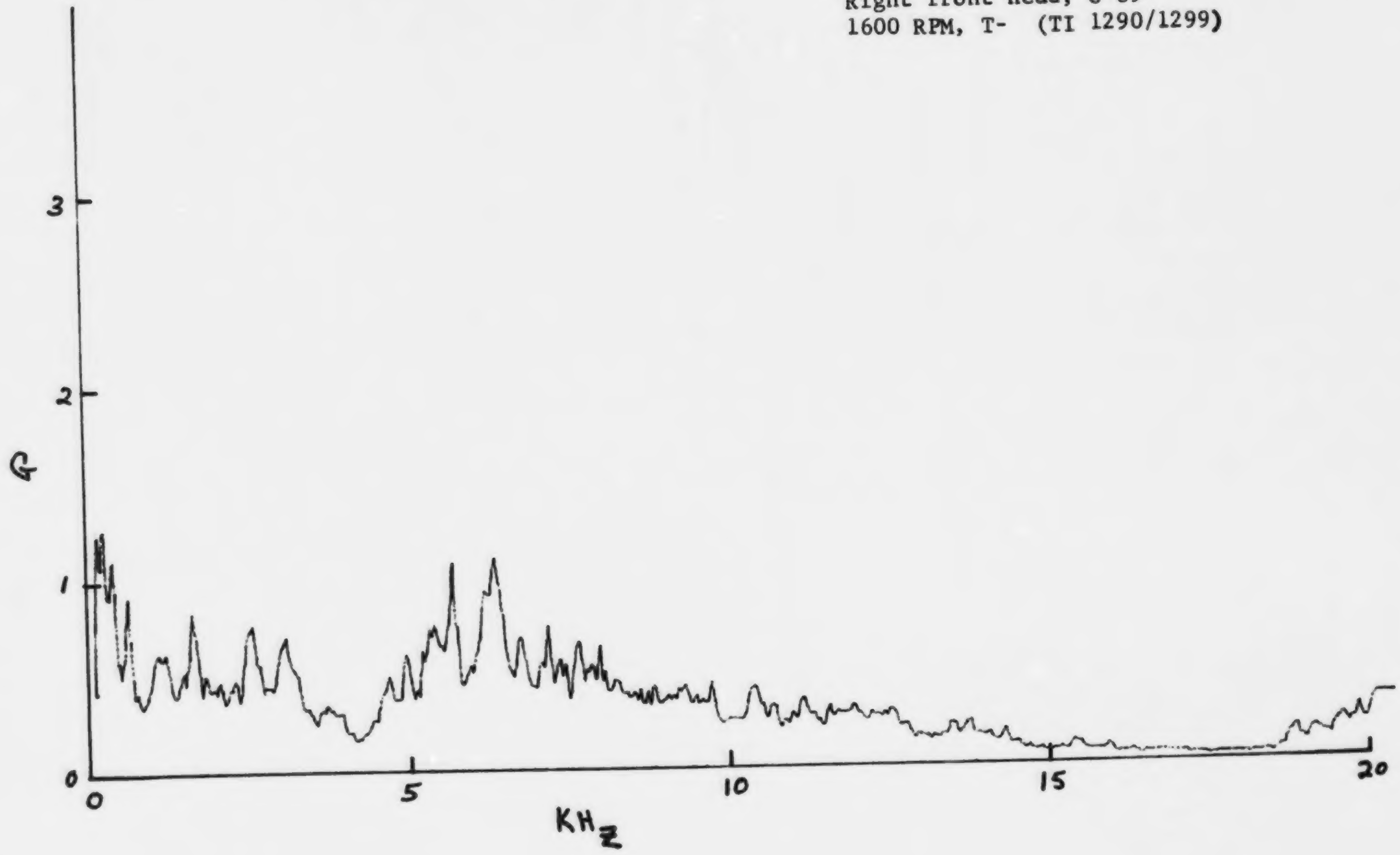
P23-5


P23 - 5 2.3 L, 4 cyl.
Rear head, C-89
1600 RPM, T- (TI 1290/1299)

P23-6

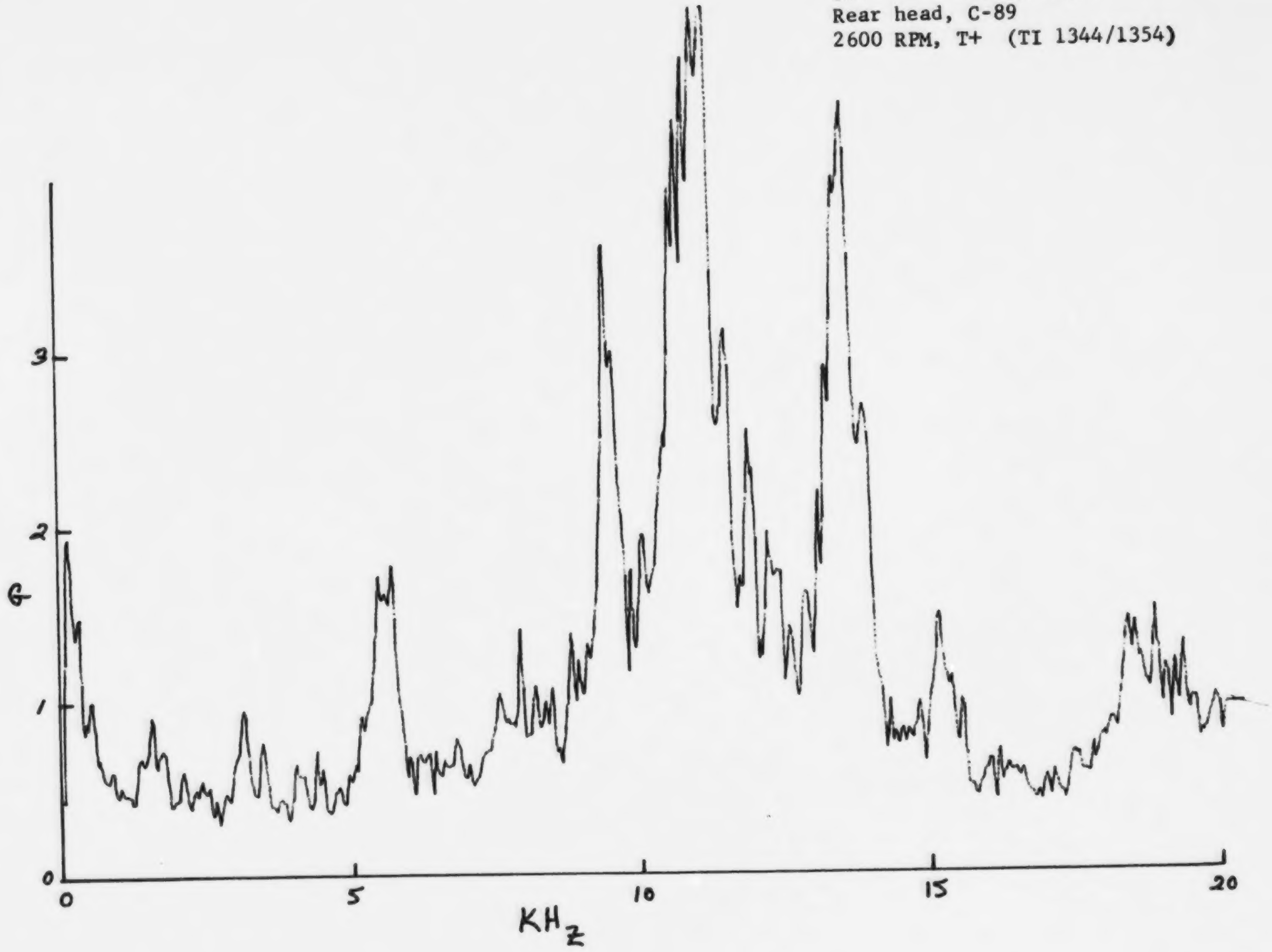

P23- 6   2.3 L, 4 cyl.
Rear block, C-89
1600 RPM, T- (TI 1290/1299)

P23-7



P23 - 7 2.3 L, 4 cyl.
Right front head, C-89
1600 RPM, T- (TI 1290/1299)

P24-5
RH

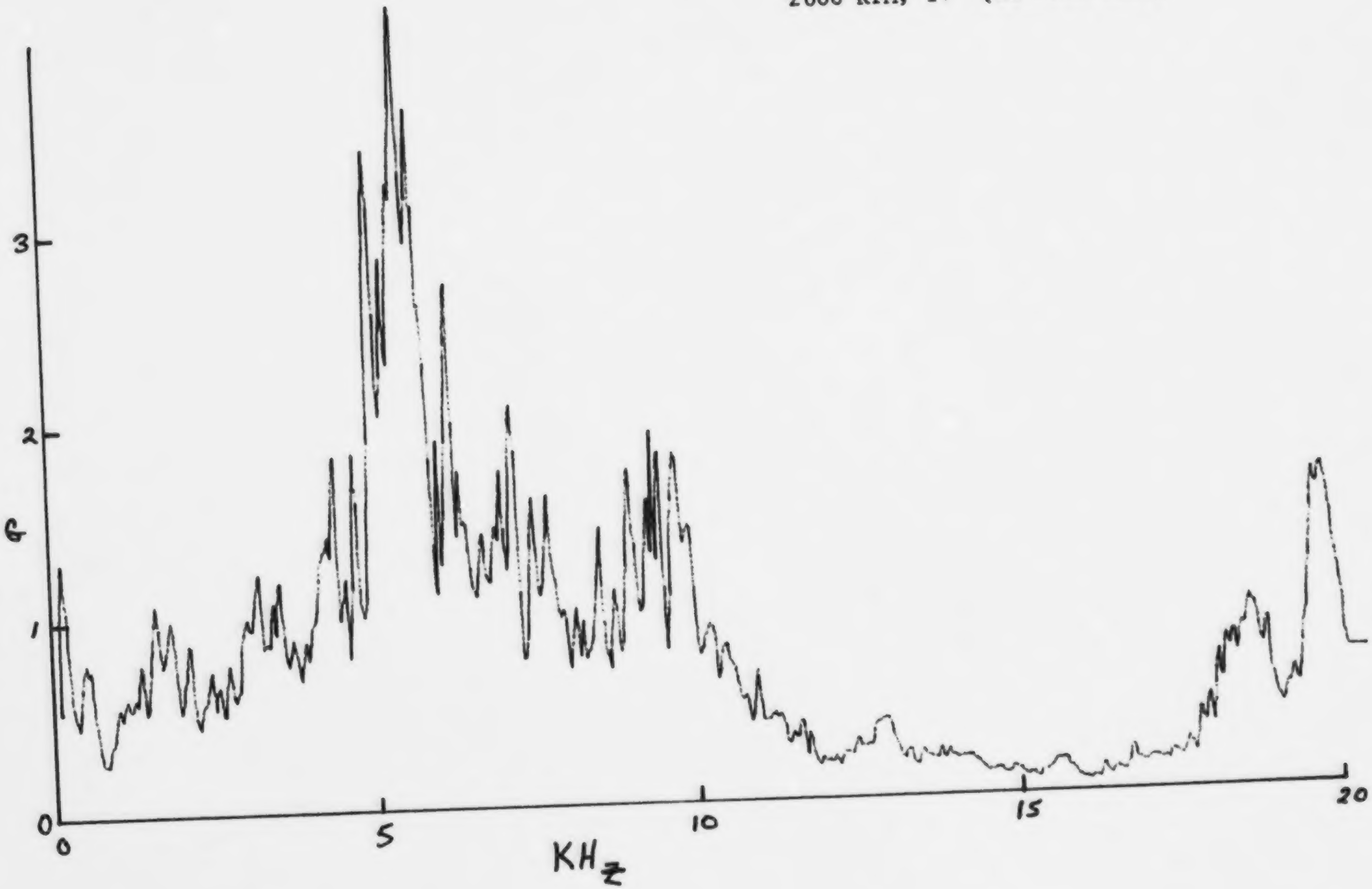


P24 - 5   2.3 L, 4cyl.
Rear head, C-89
2600 RPM, T+ (TI 1344/1354)

P24-6

RB

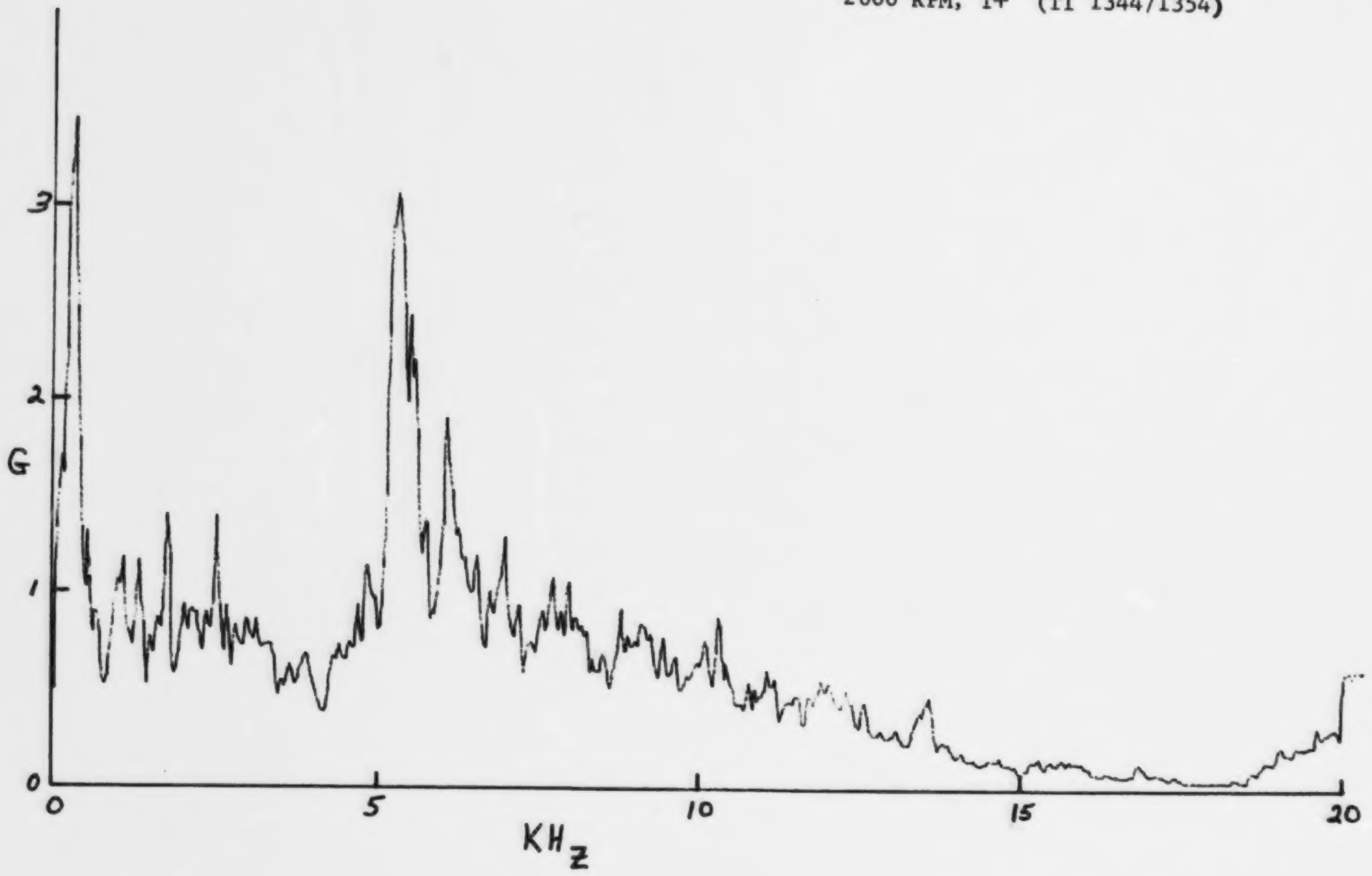
P24 - 6   2.3 L, 4 cyl.
Rear block, C-89
2600 RPM, T+ (TI 1344/1354)



P24-7

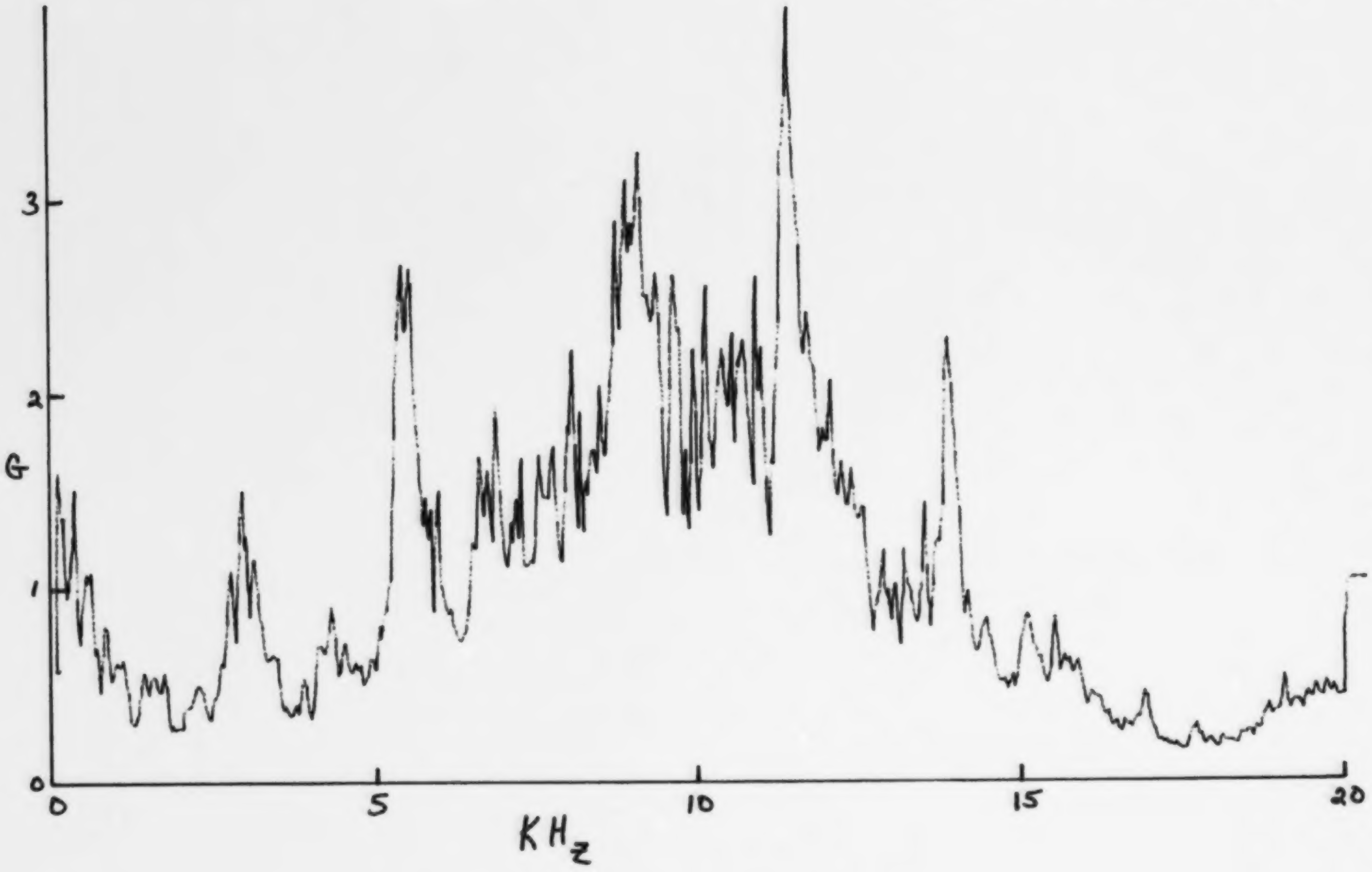
CFH

P24 - 7 2.3 L, 4 cyl.
Right front head, C-89
2600 RPM, T+ (TI 1344/1354)



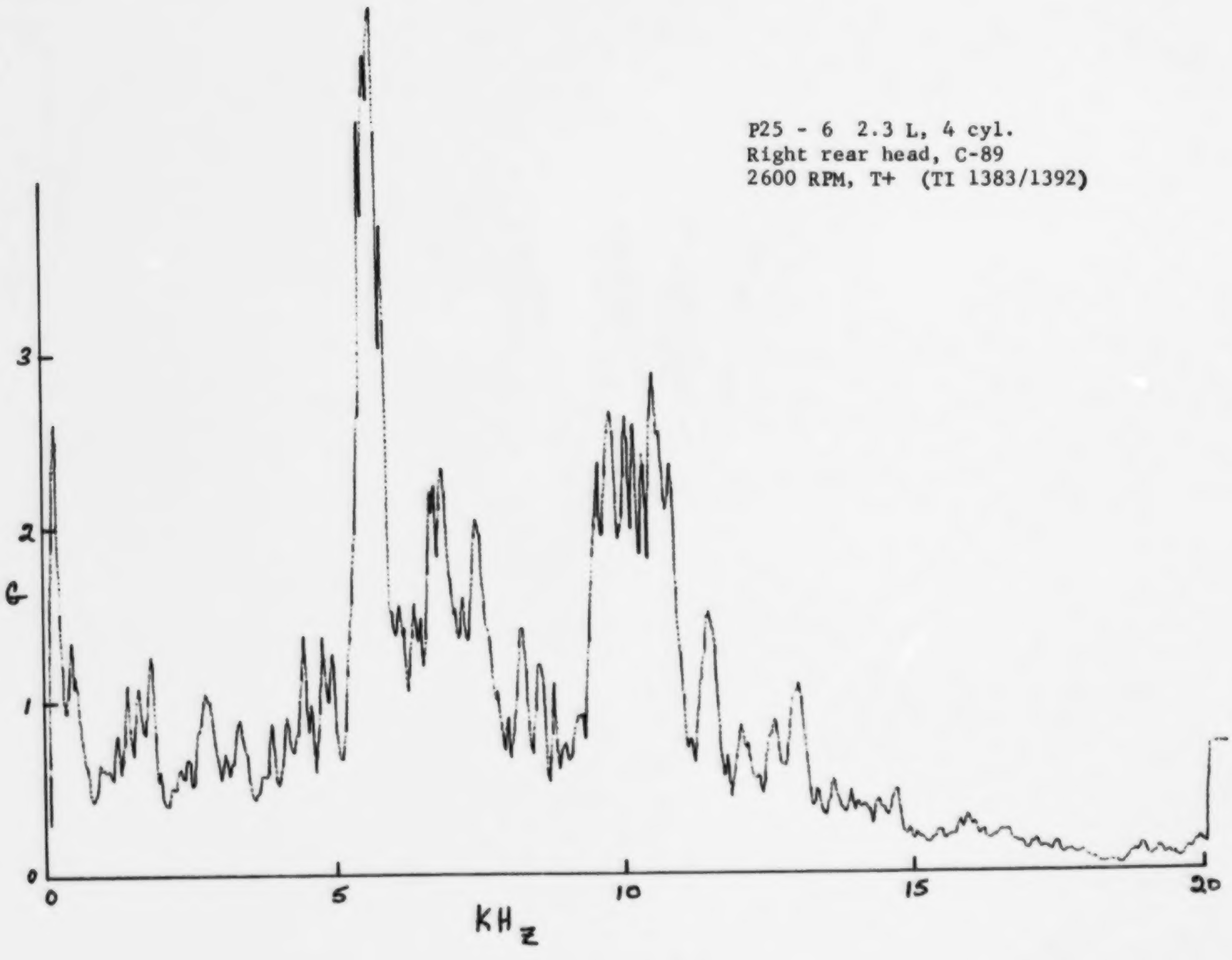
P25-5

P25 - 5 2.3 L, 4 cyl.
Intake Manifold, C-89
2600 RPM, T+ (TI 1383/1392)



P25-6

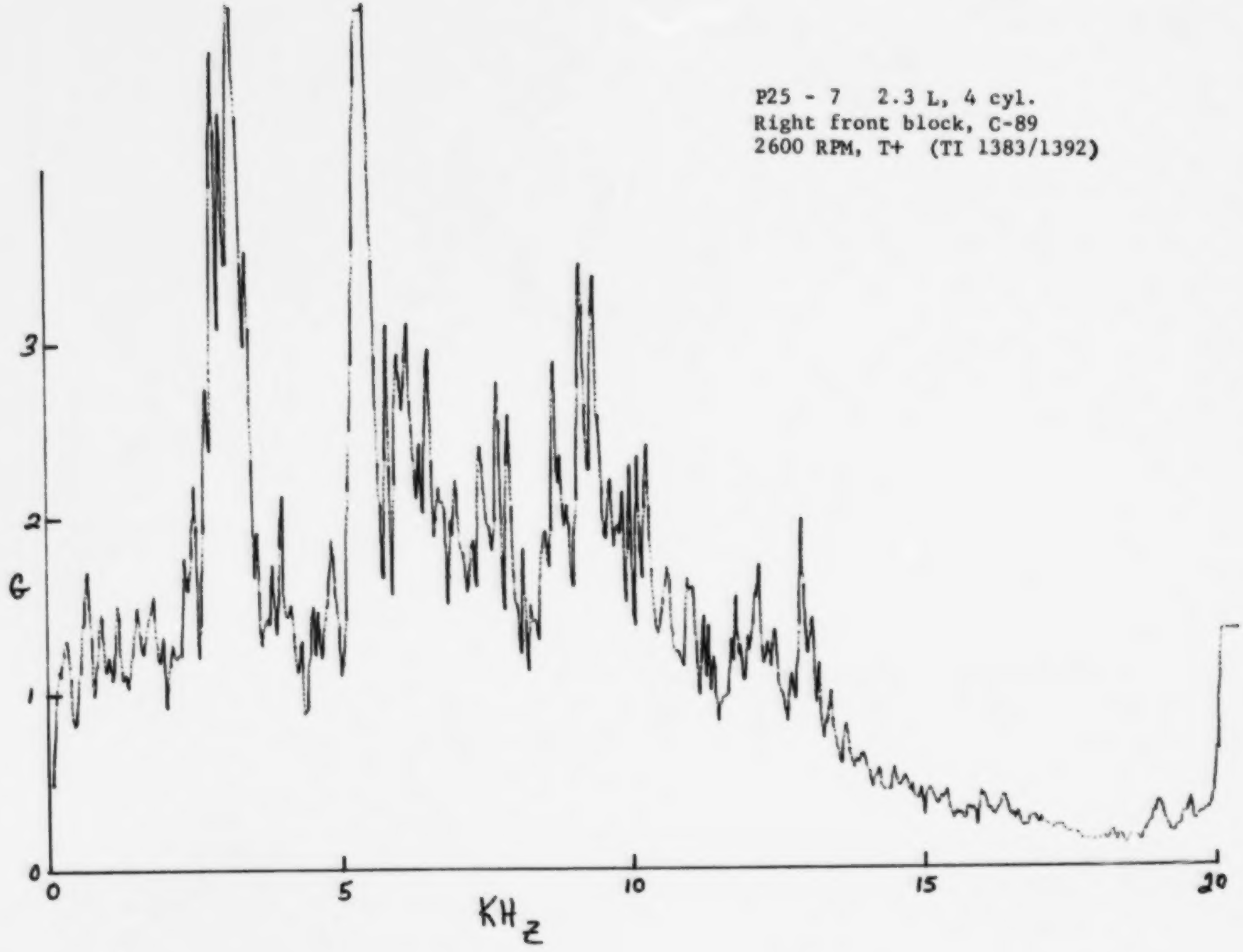
RR11



P25 - 6 2.3 L, 4 cyl.
Right rear head, C-89
2600 RPM, T+ (TI 1383/1392)

P25-7

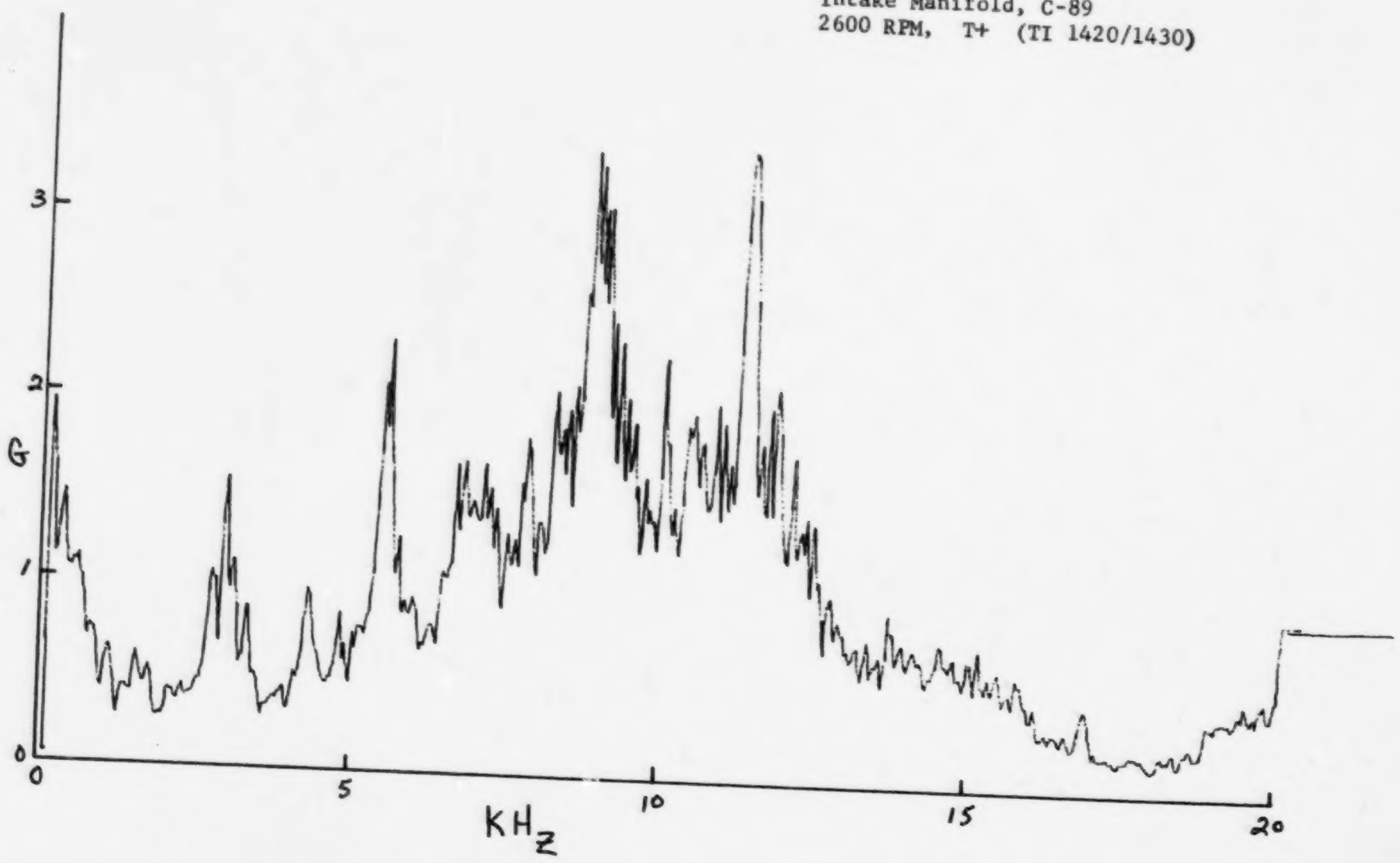
RF 3



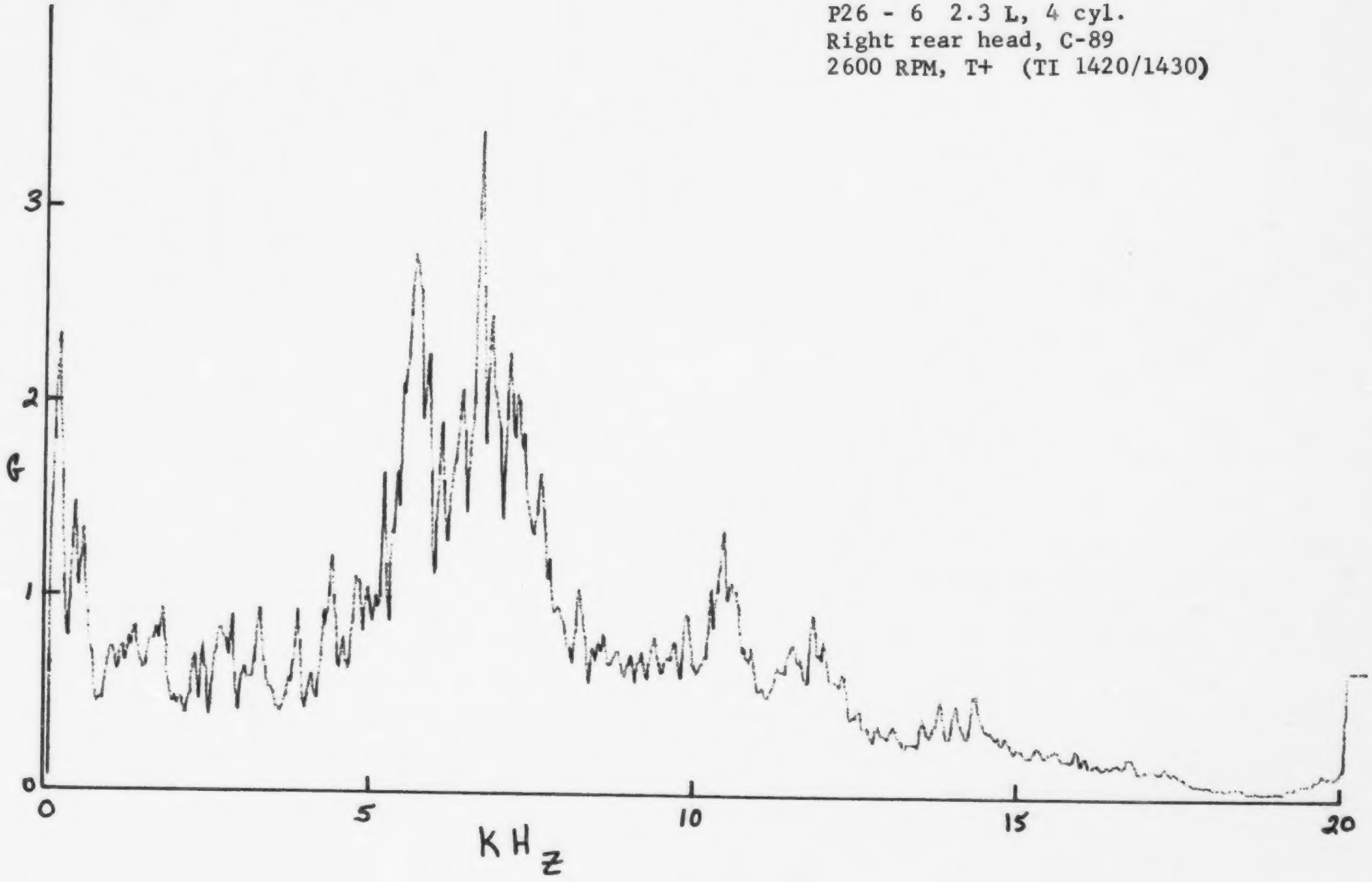
P25 - 7   2.3 L, 4 cyl.
Right front block, C-89
2600 RPM, T+ (TI 1383/1392)

P26-5

P26 - 5   2.3 L, 4 cyl.
Intake Manifold, C-89
2600 RPM, T+ (TI 1420/1430)

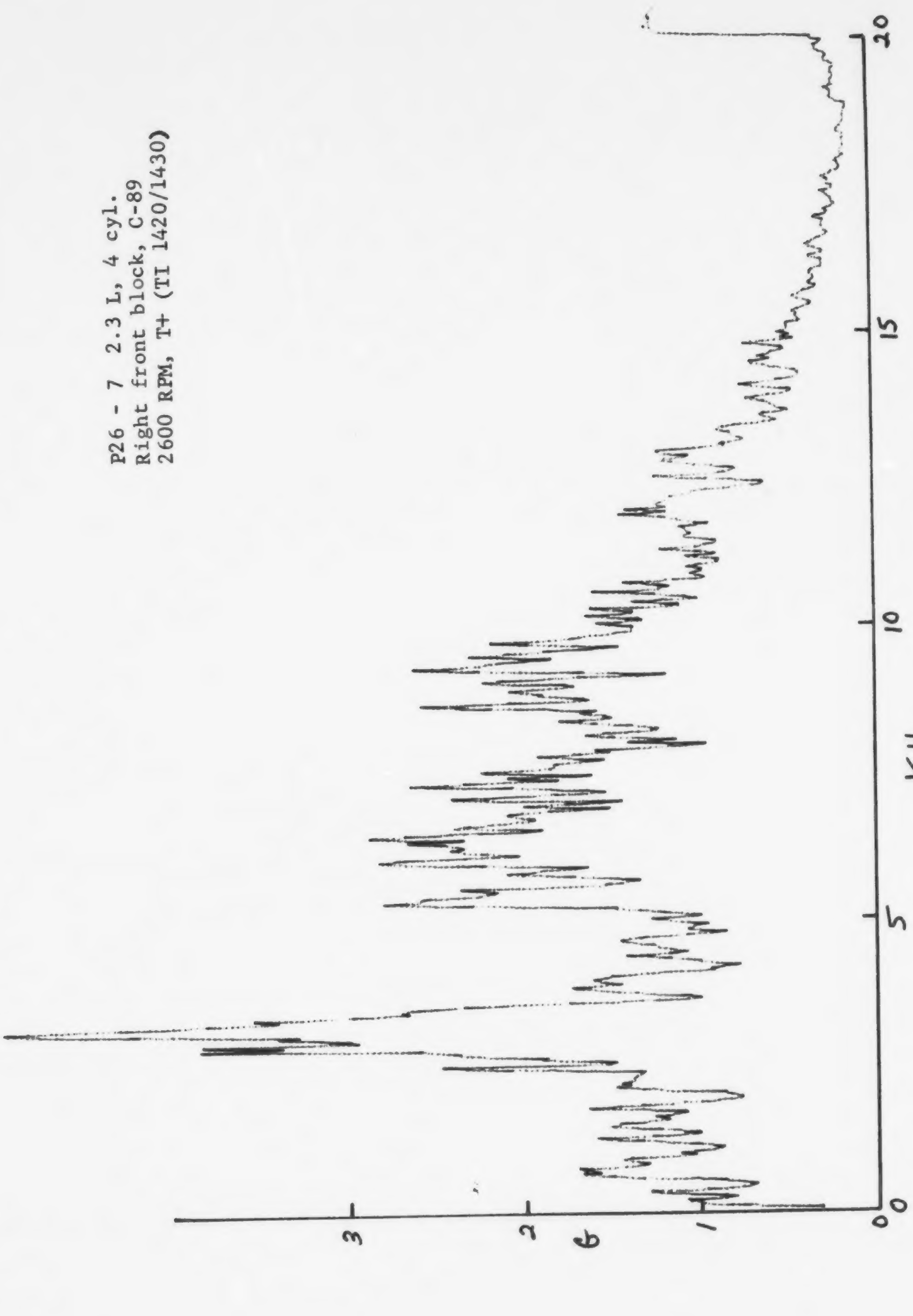


P26-6



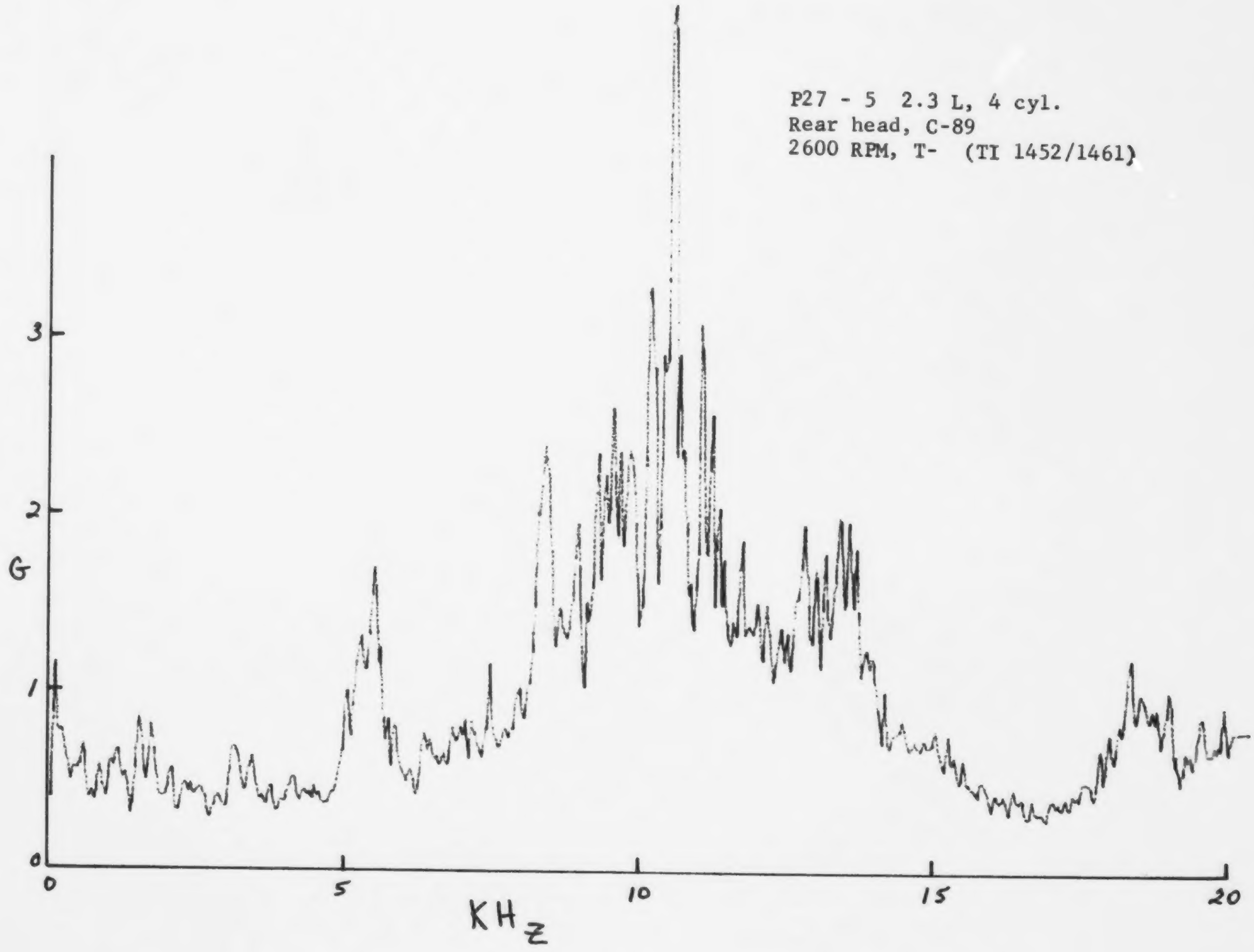
P26 - 6 2.3 L, 4 cyl.
Right rear head, C-89
2600 RPM, T+ (TI 1420/1430)

P26-7



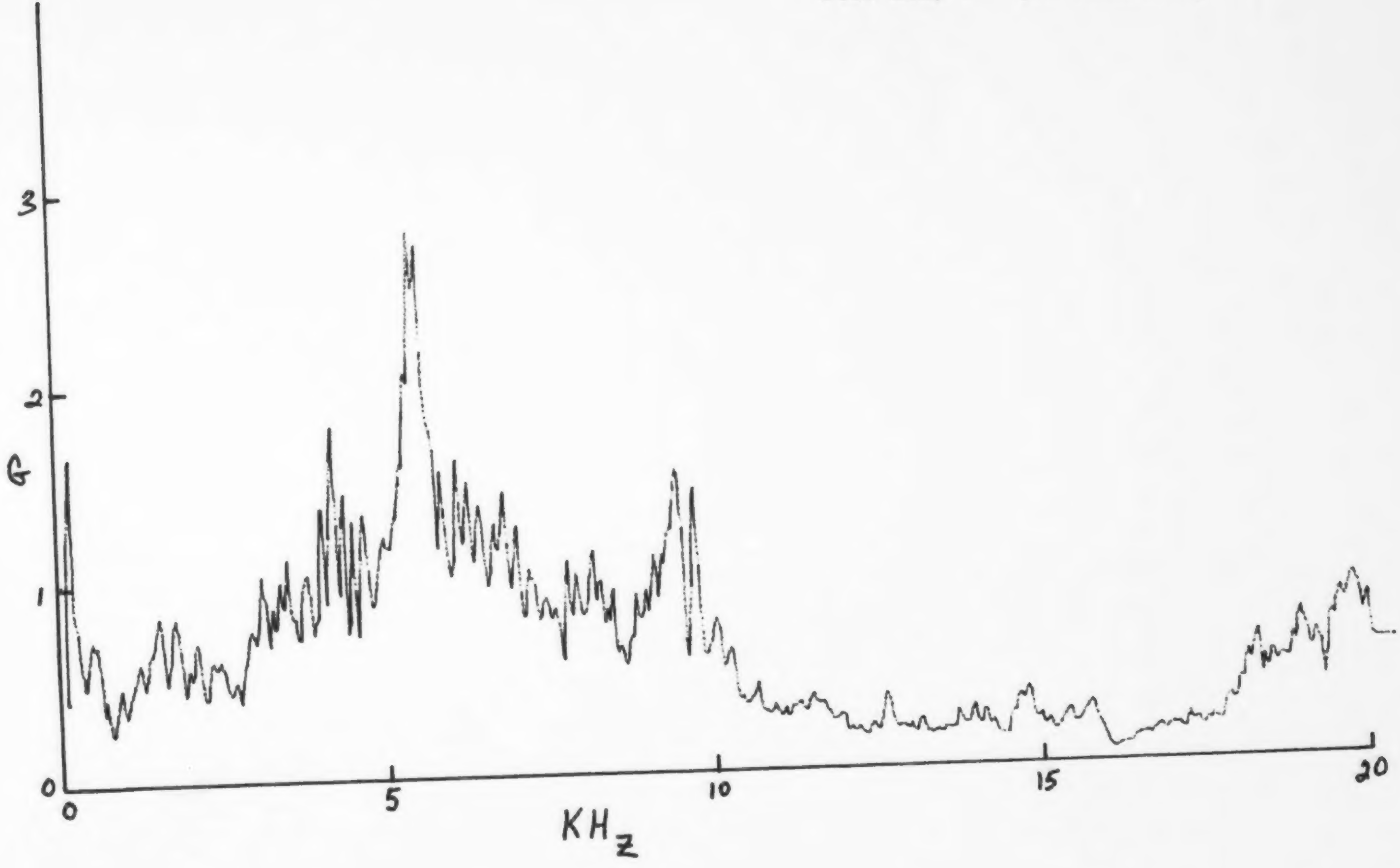
P26 - 7 2.3 L, 4 cyl.
Right front block, C-89
2600 RPM, T+ (TI 1420/1430)

P27-5



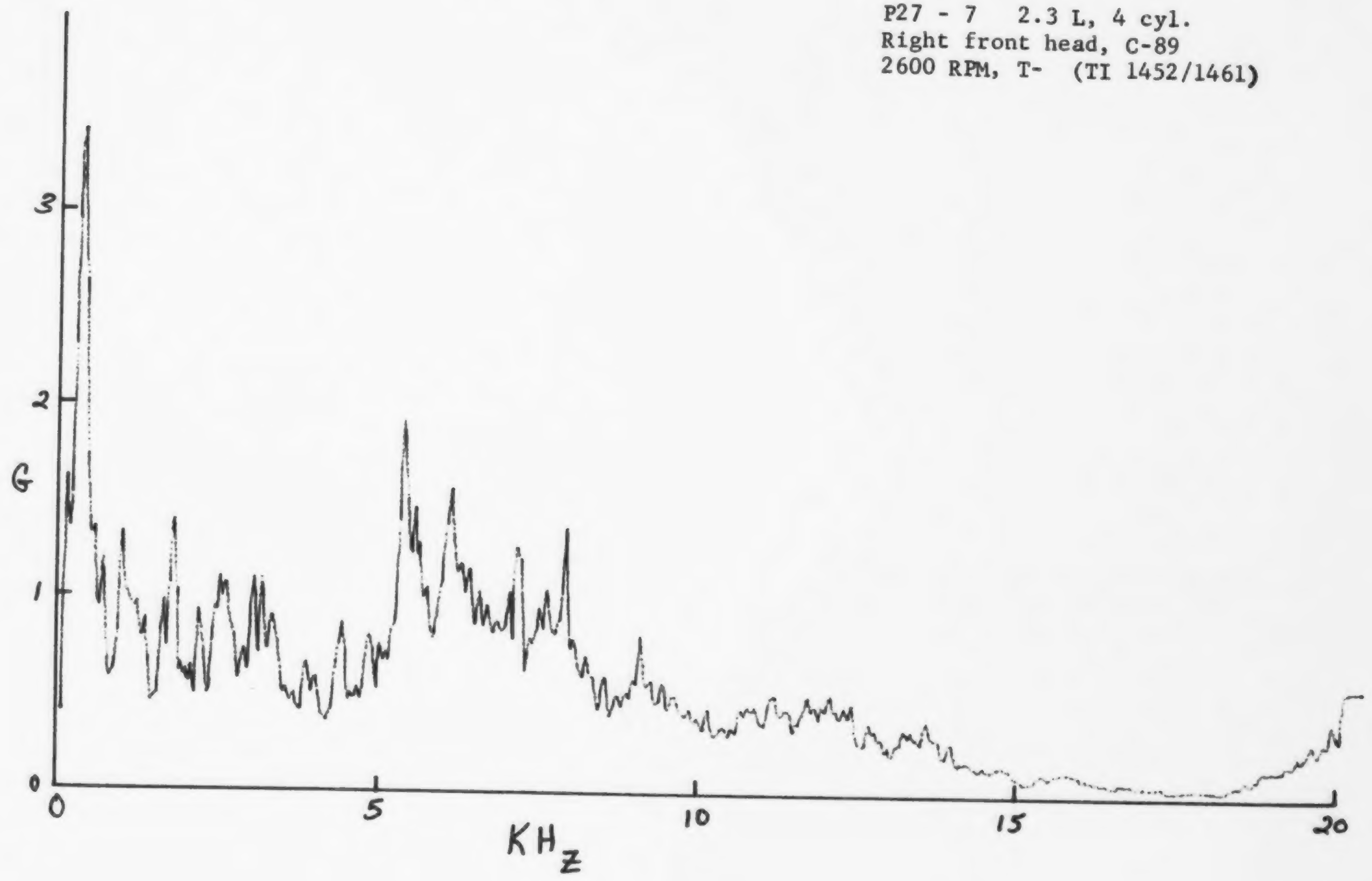
P27 - 5 2.3 L, 4 cyl.
Rear head, C-89
2600 RPM, T- (TI 1452/1461)

P27-6



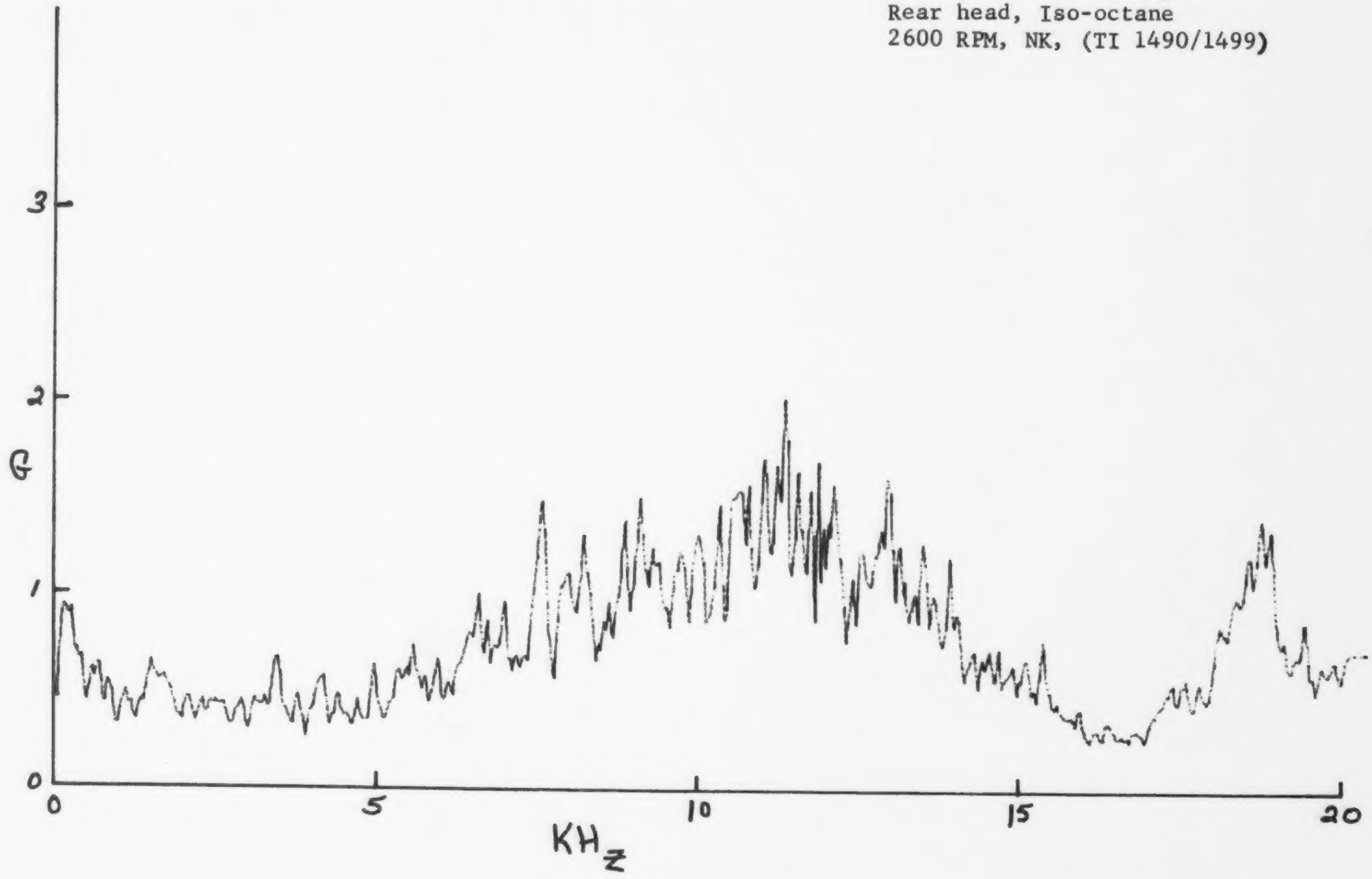
P27 - 6 2.3 L, 4 cyl.
Rear block, C-89
2600 RPM, T- (TI 1452/1461)

P27-7



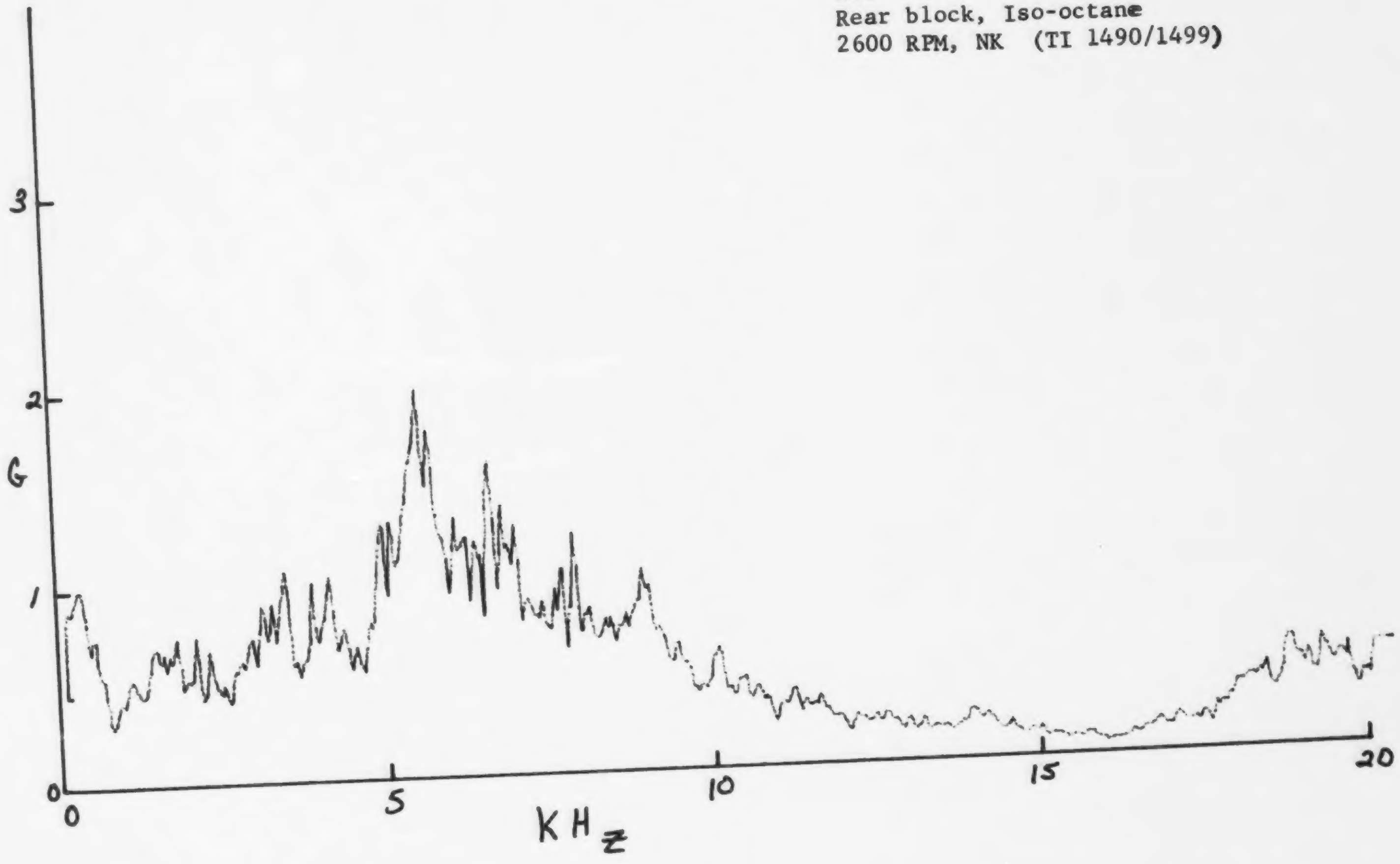
P27 - 7   2.3 L, 4 cyl.
Right front head, C-89
2600 RPM, T- (TI 1452/1461)

P28-5



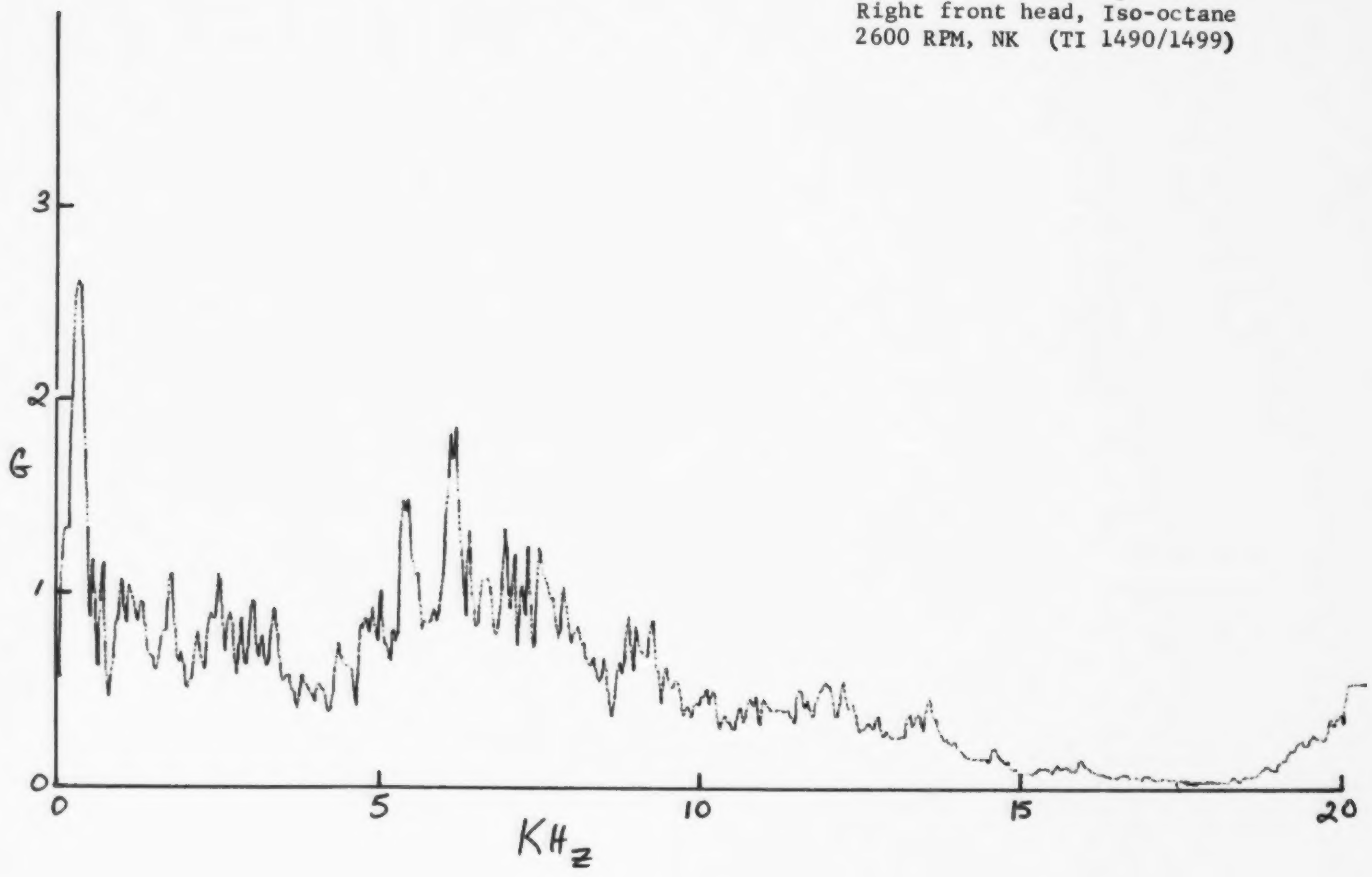
P28 - 5 2.3 L, 4 cyl.
Rear head, Iso-octane
2600 RPM, NK, (TI 1490/1499)

P28-6



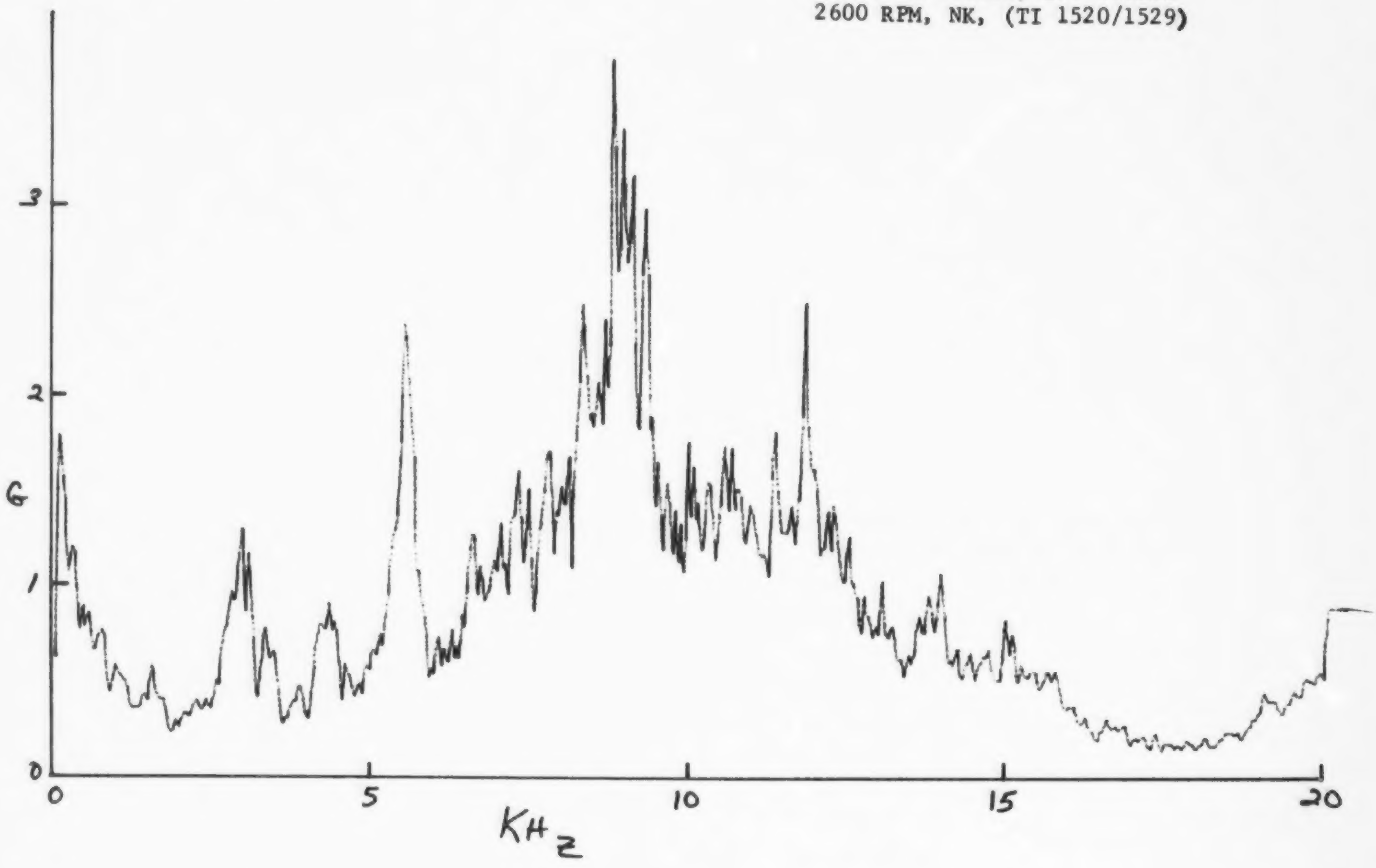
P28 - 6   2.3 L, 4 cyl.
Rear block, Iso-octane
2600 RPM, NK (TI 1490/1499)

P28-7



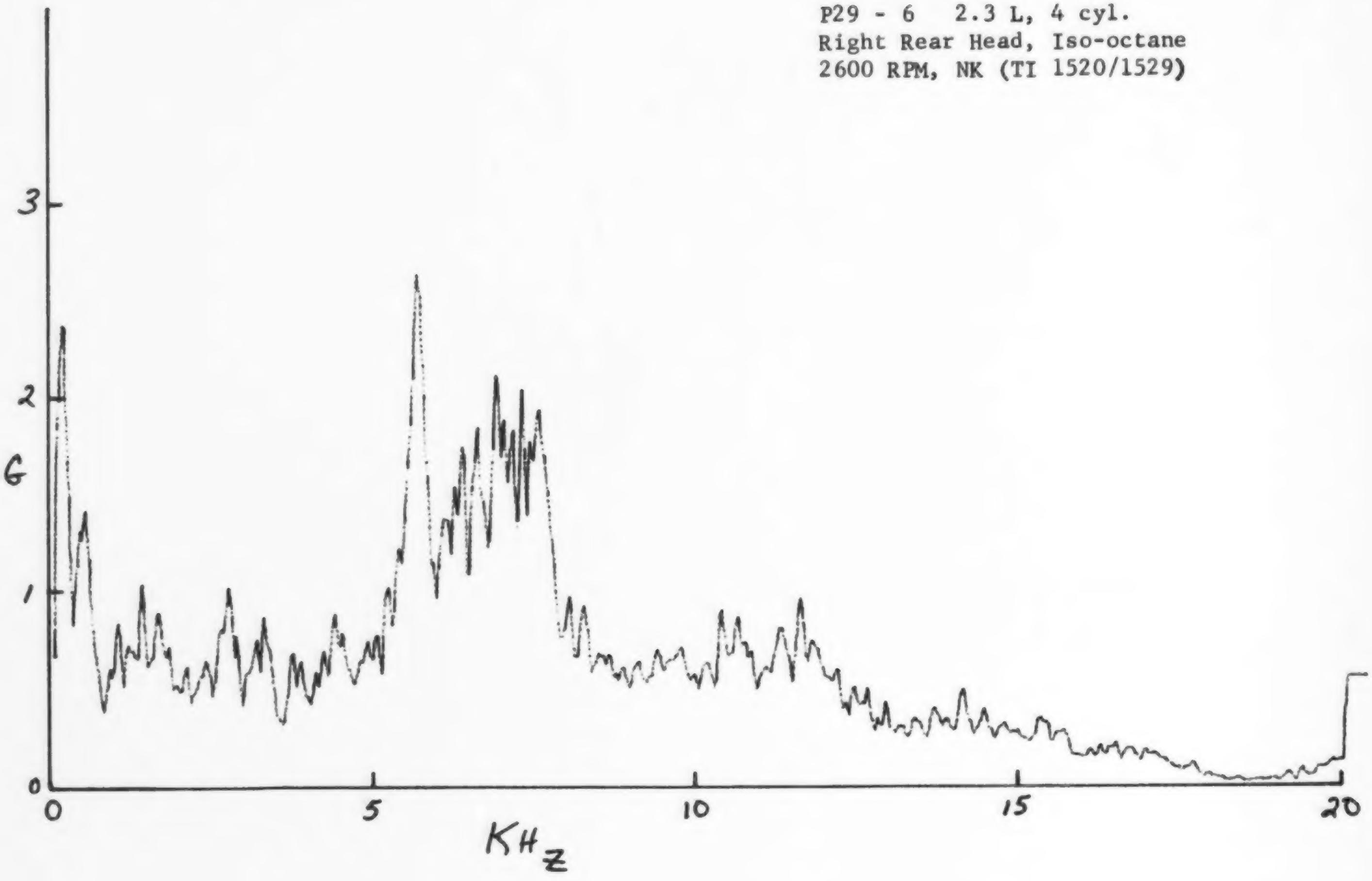
P28 - 7 2.3 L, 4 cyl.
Right front head, Iso-octane
2600 RPM, NK (TI 1490/1499)

P29-5



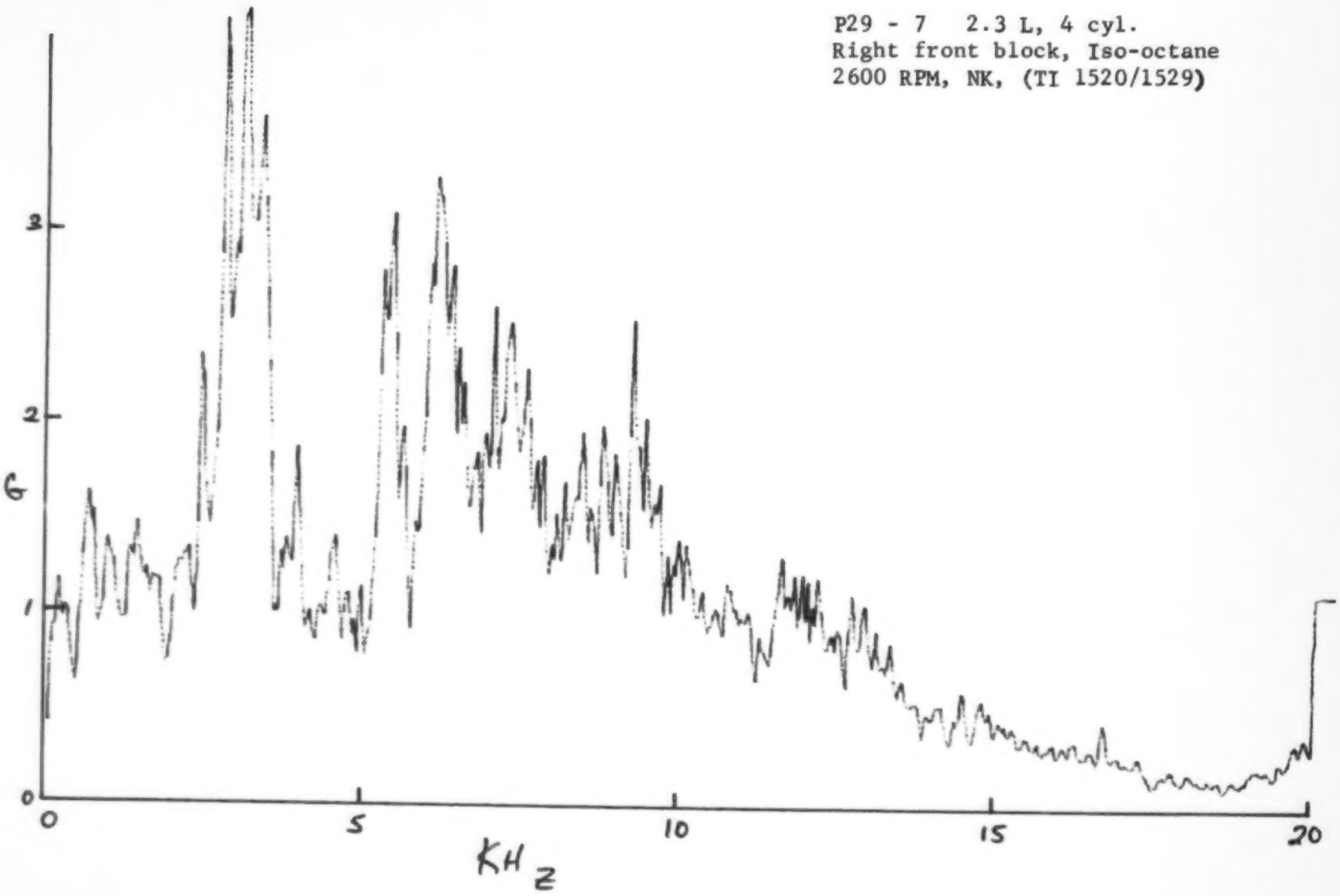
P29 - 5 2.3 L, 4 cyl.
Intake Manifold, Iso-octane
2600 RPM, NK, (TI 1520/1529)

P29-6

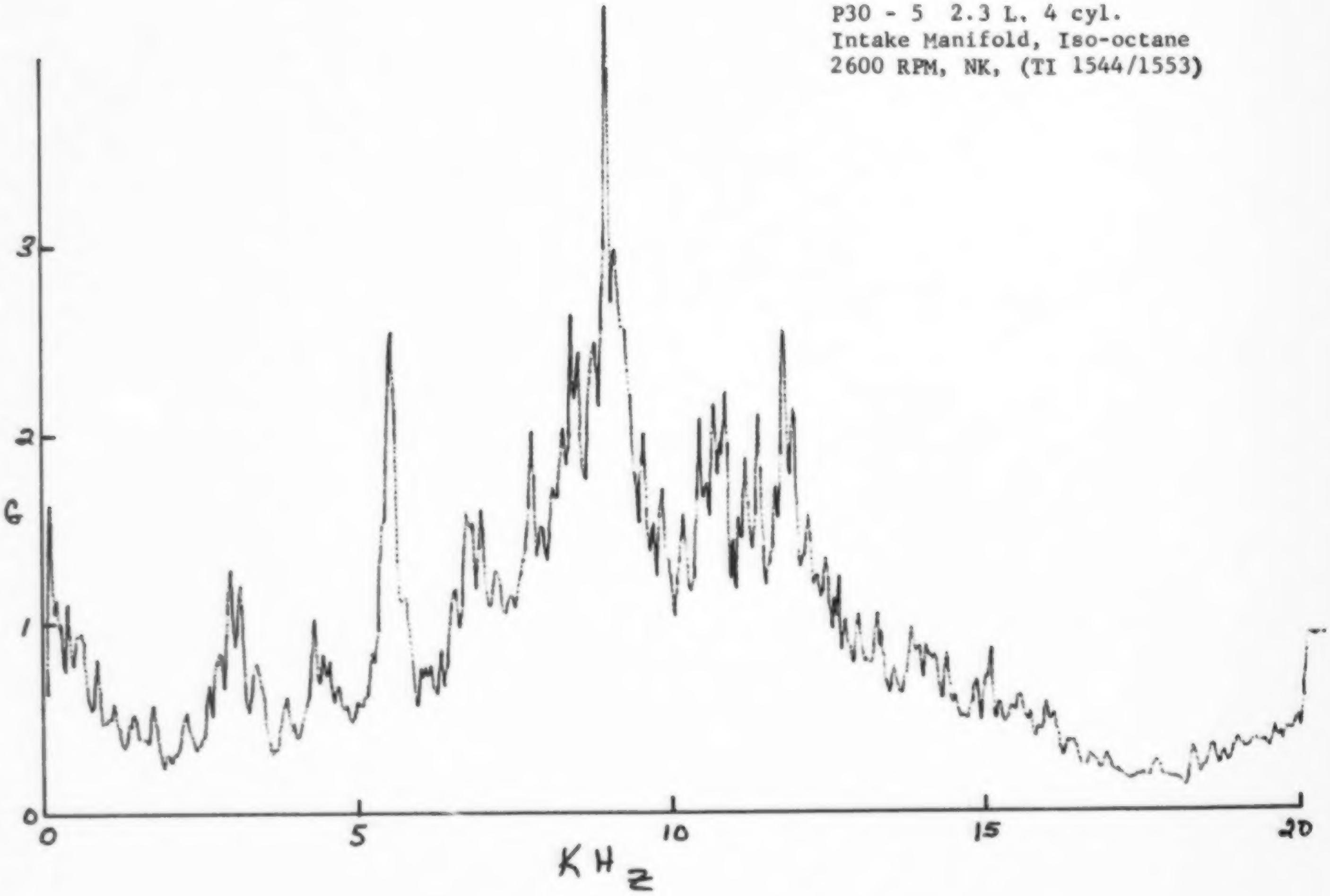


P29 - 6   2.3 L, 4 cyl.
Right Rear Head, Iso-octane
2600 RPM, NK (TI 1520/1529)

P29-7

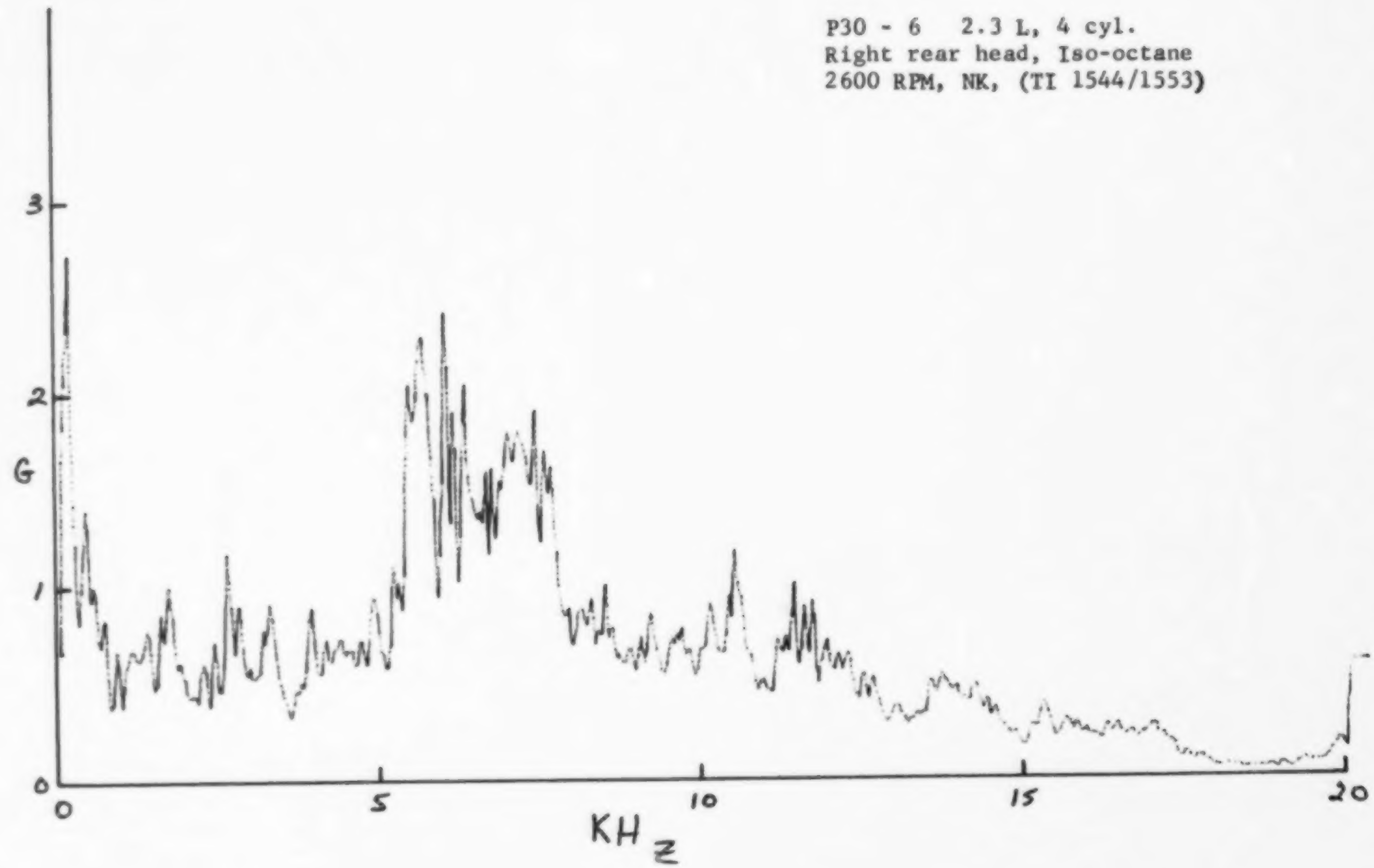

P29 - 7   2.3 L, 4 cyl.
Right front block, Iso-octane
2600 RPM, NK, (TI 1520/1529)

P30-5



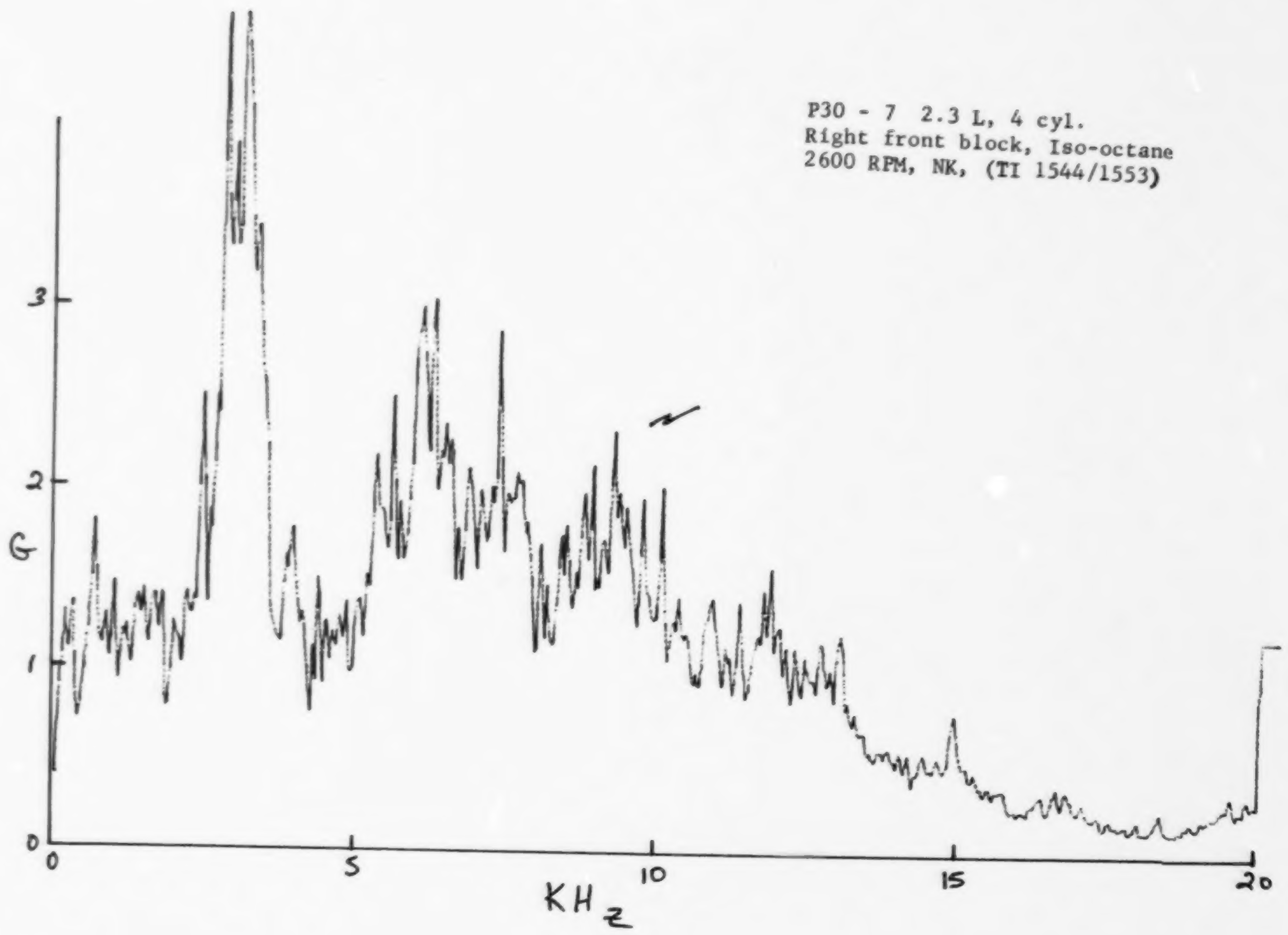
P30 - 5 2.3 L. 4 cyl.
Intake Manifold, Iso-octane
2600 RPM, NK, (TI 1544/1553)

P30-6



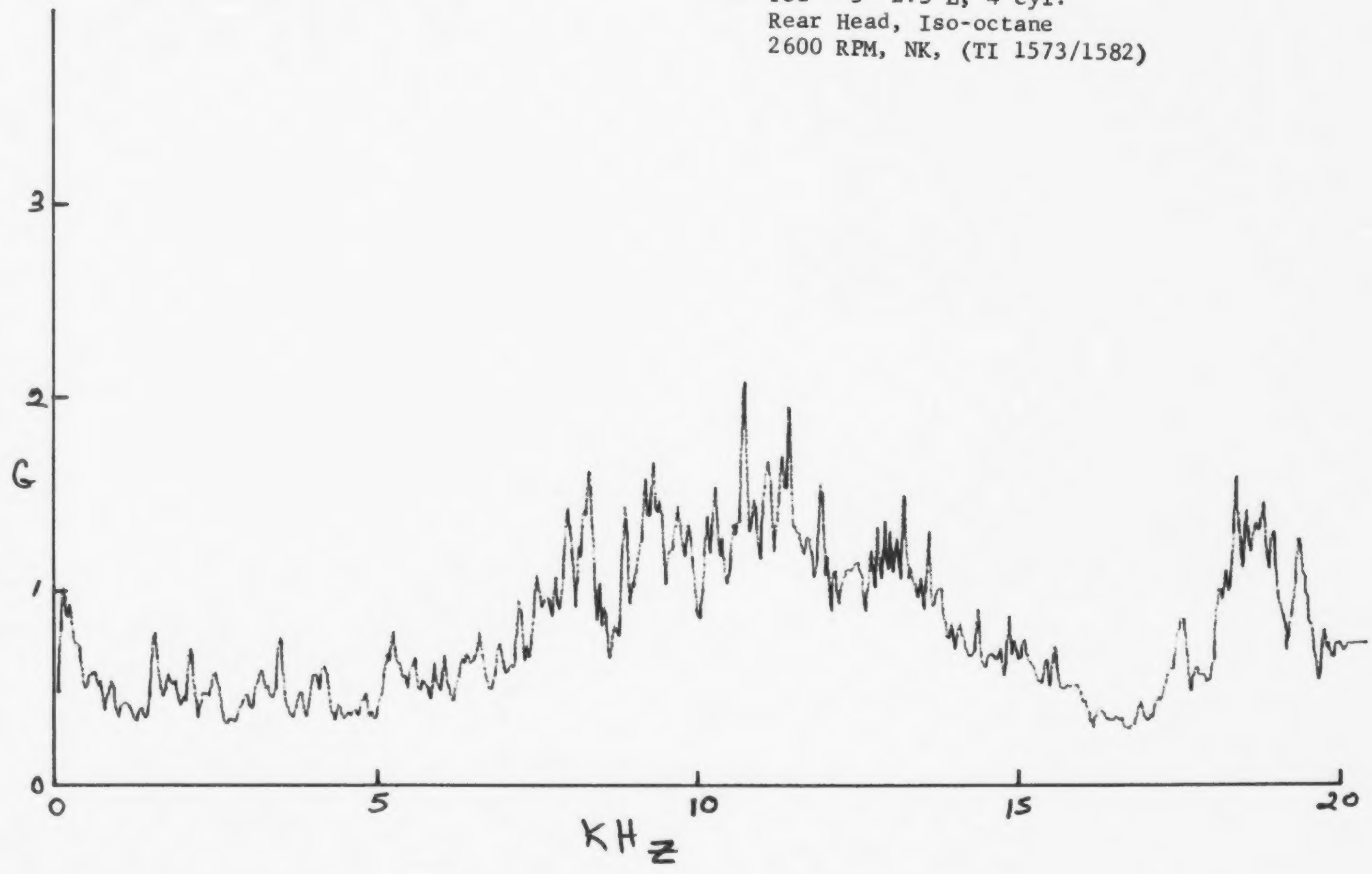
P30 - 6   2.3 L, 4 cyl.
Right rear head, Iso-octane
2600 RPM, NK, (TI 1544/1553)

P30-7



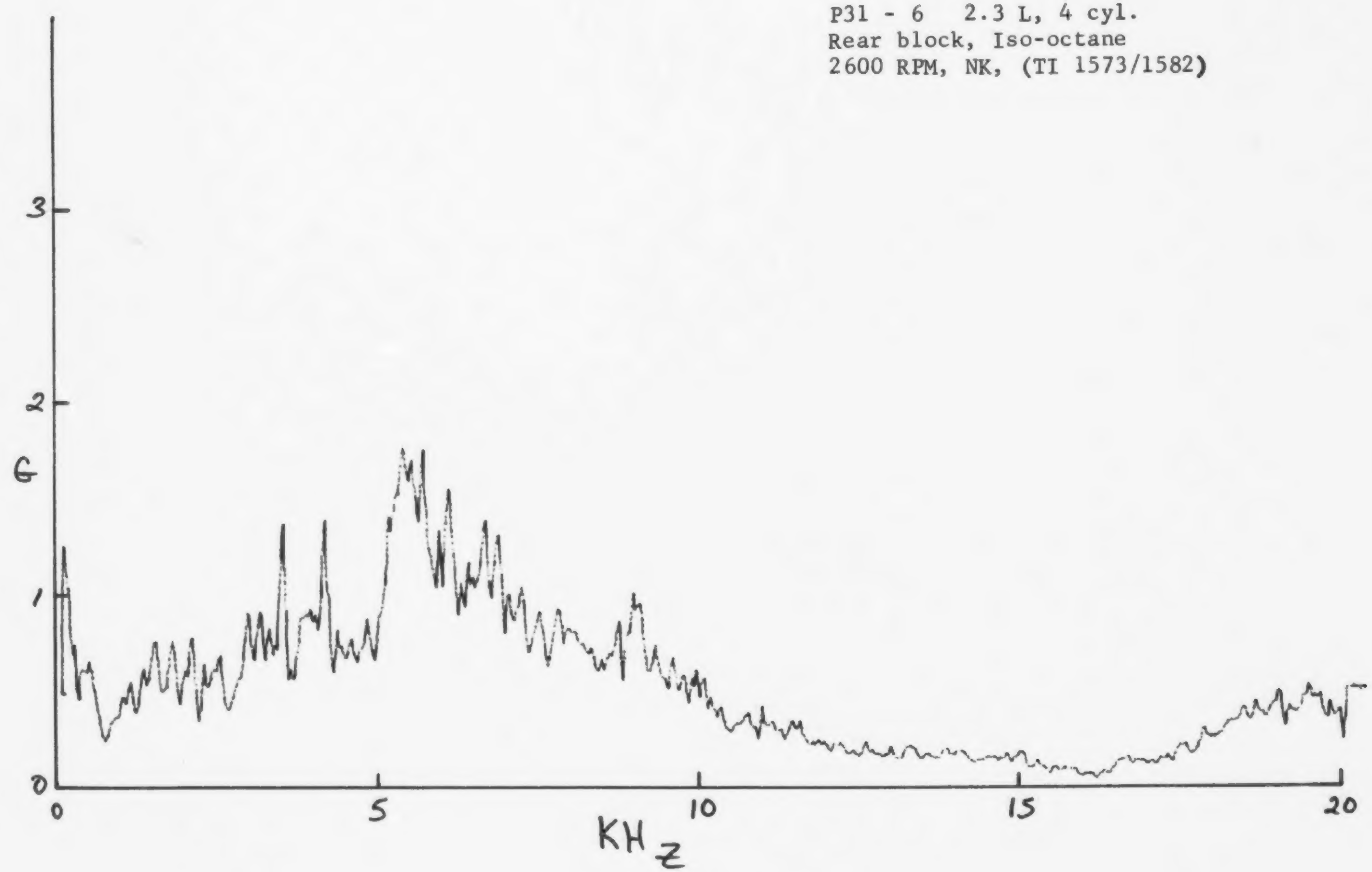
P30 - 7 2.3 L, 4 cyl.
Right front block, Iso-octane
2600 RPM, NK, (TI 1544/1553)

P31-5



P31 - 5 2.3 L, 4 cyl.
Rear Head, Iso-octane
2600 RPM, NK, (TI 1573/1582)

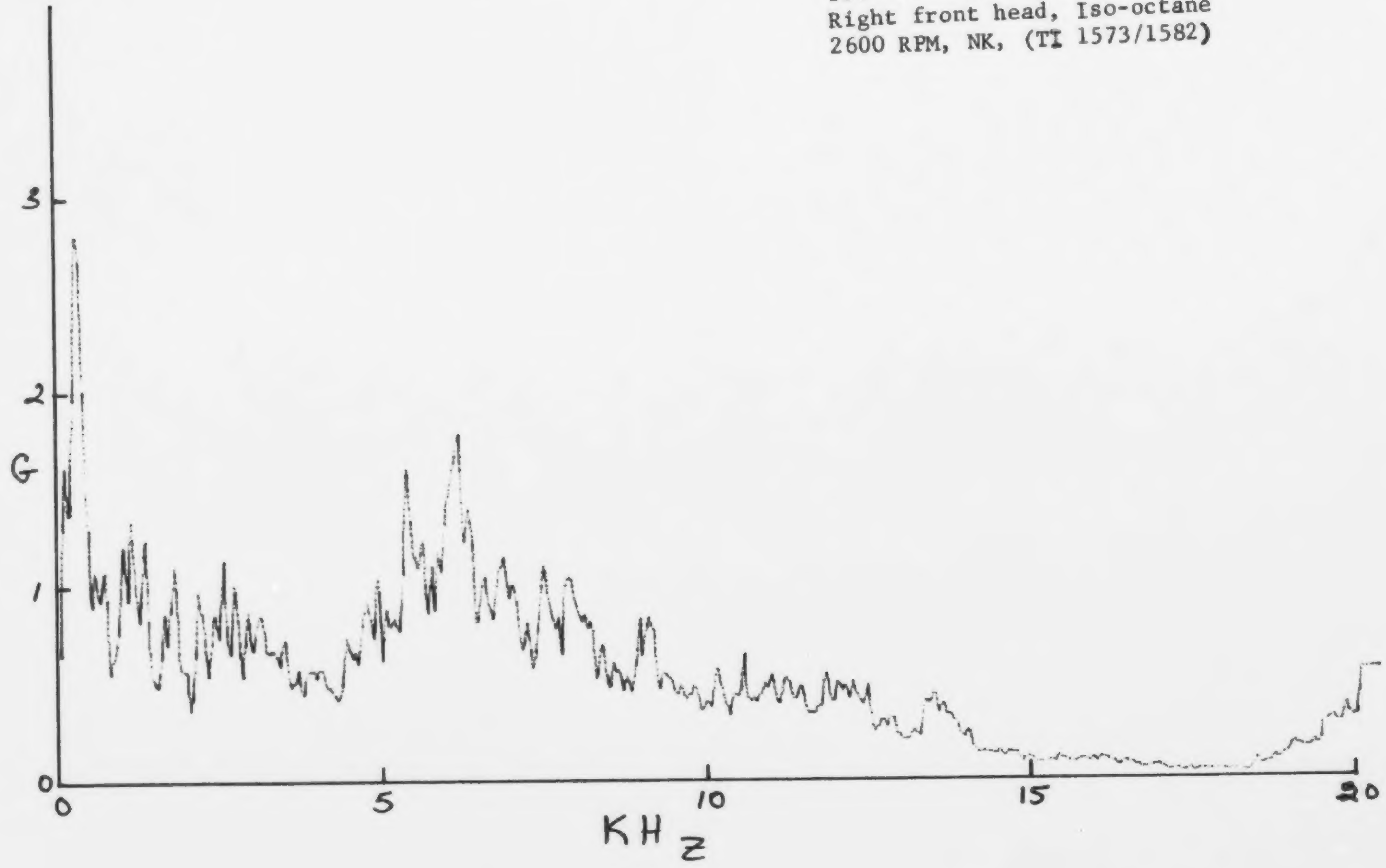
P31-6



P31 - 6   2.3 L, 4 cyl.
Rear block, Iso-octane
2600 RPM, NK, (TI 1573/1582)

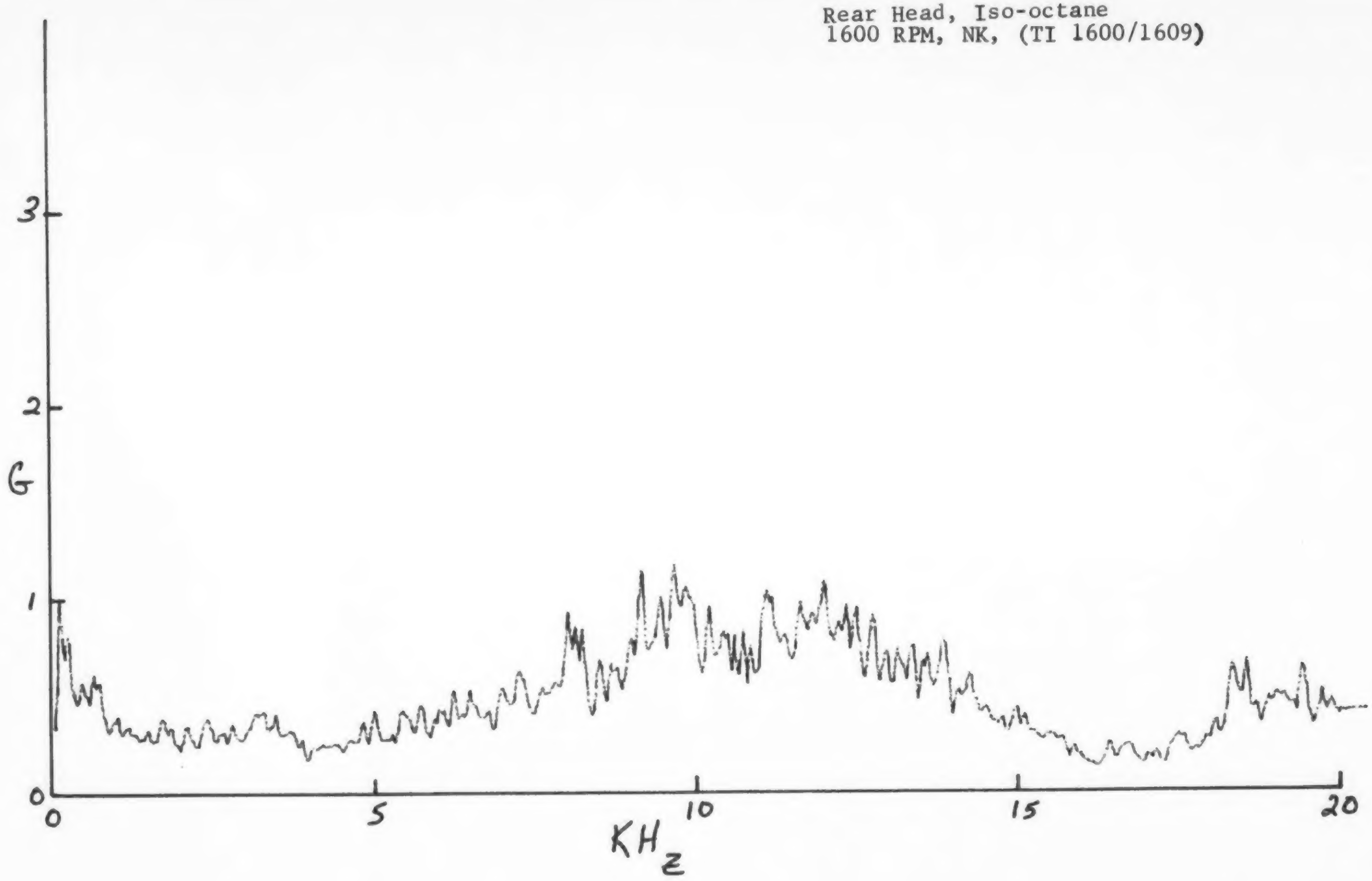
P31-7

P31 - 7   2.3 L, 4 cyl.
Right front head, Iso-octane
2600 RPM, NK, (TI 1573/1582)

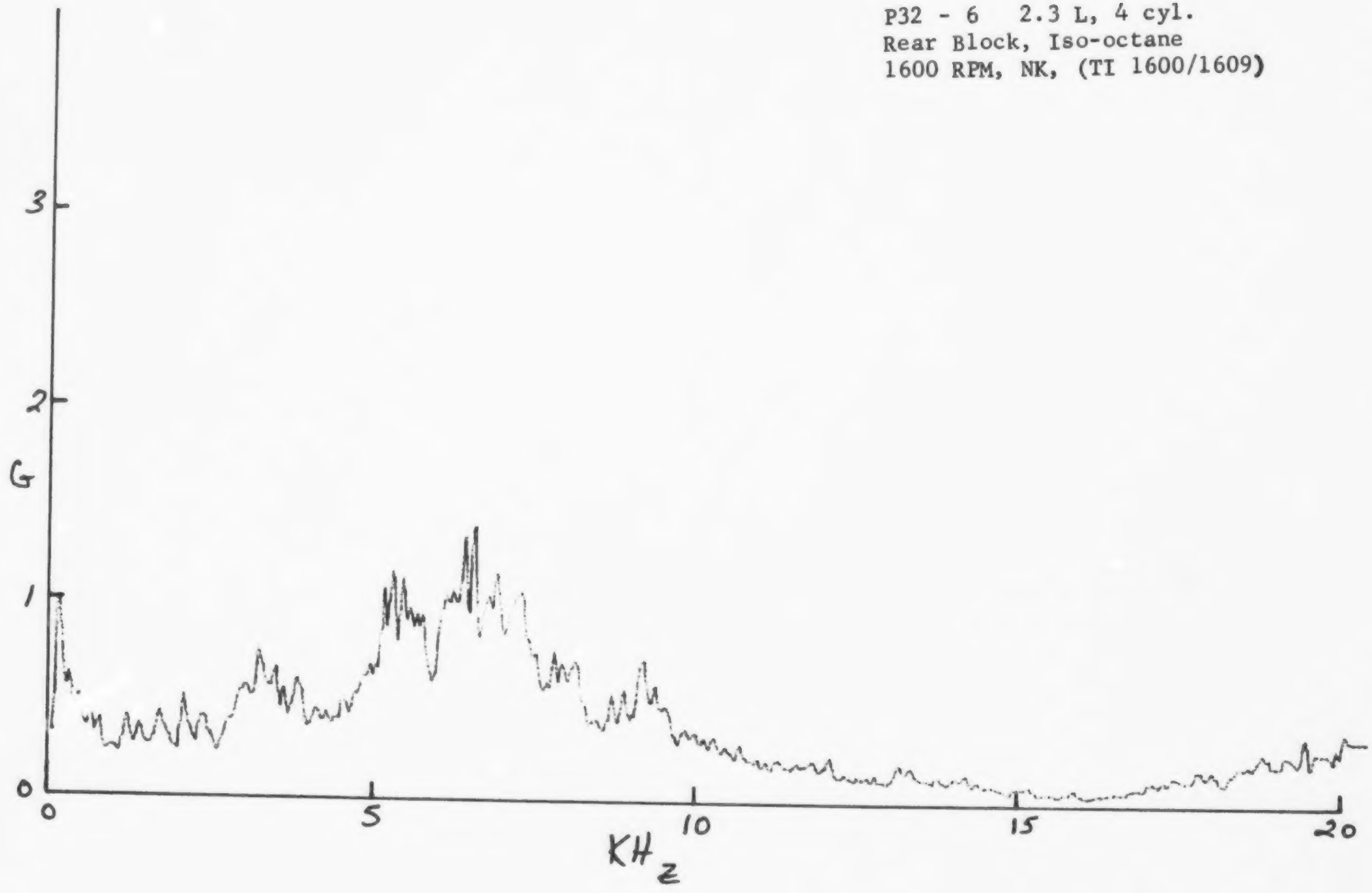


P32-5

P32 - 5   2.3 L, 4 cyl.
Rear Head, Iso-octane
1600 RPM, NK, (TI 1600/1609)

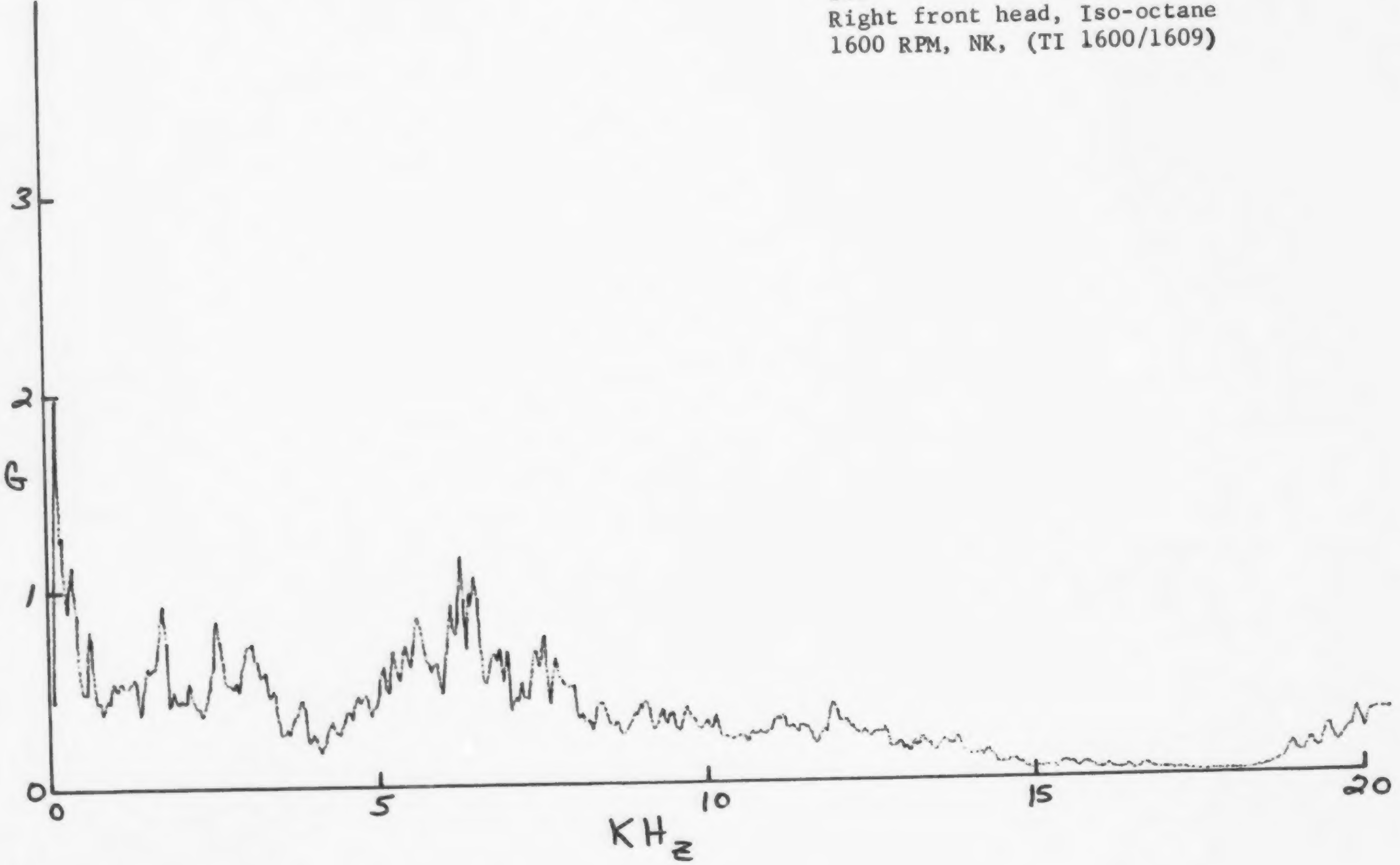


P32- 6



P32 - 6   2.3 L, 4 cyl.
Rear Block, Iso-octane
1600 RPM, NK, (TI 1600/1609)

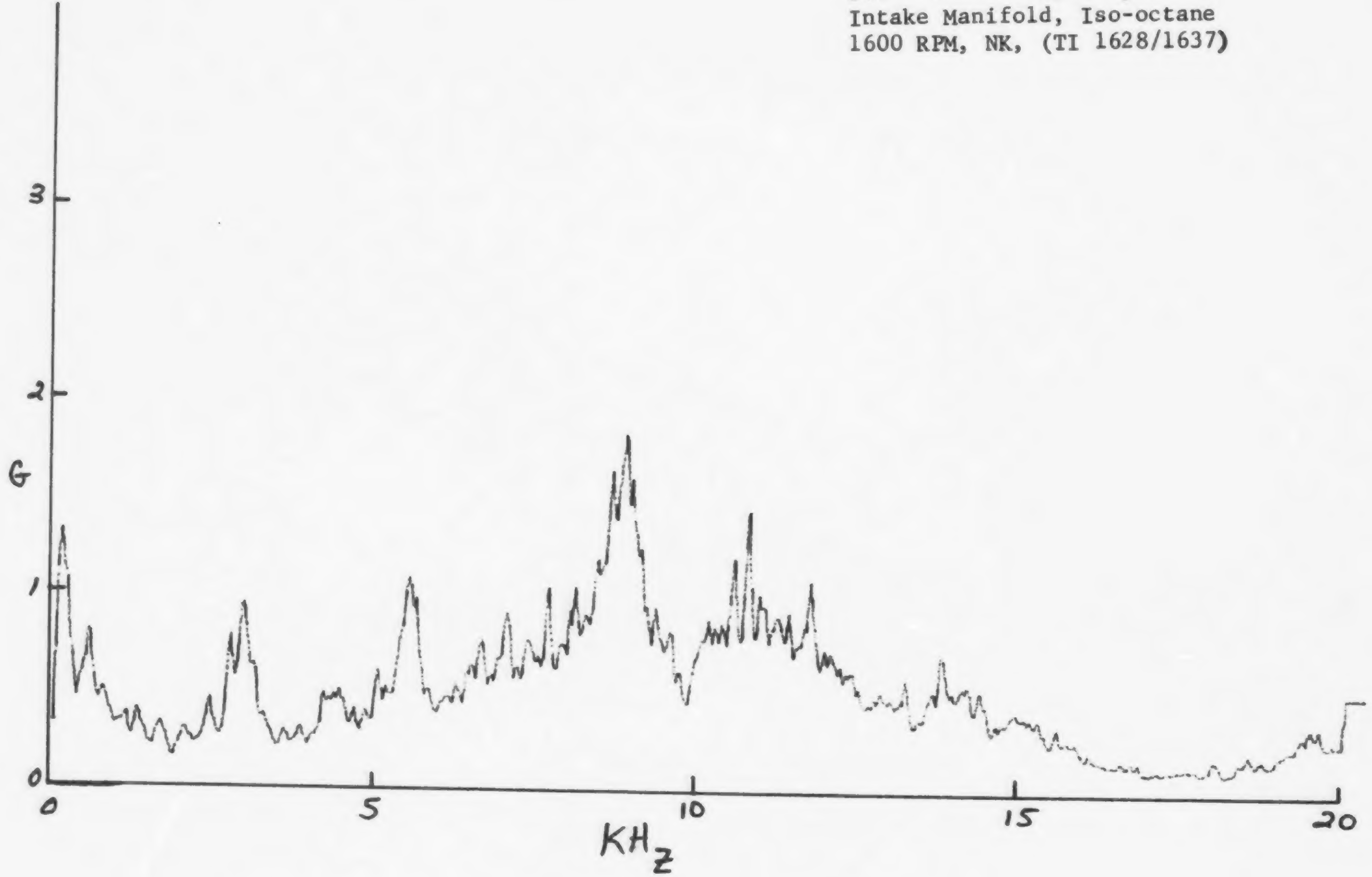
P32-7



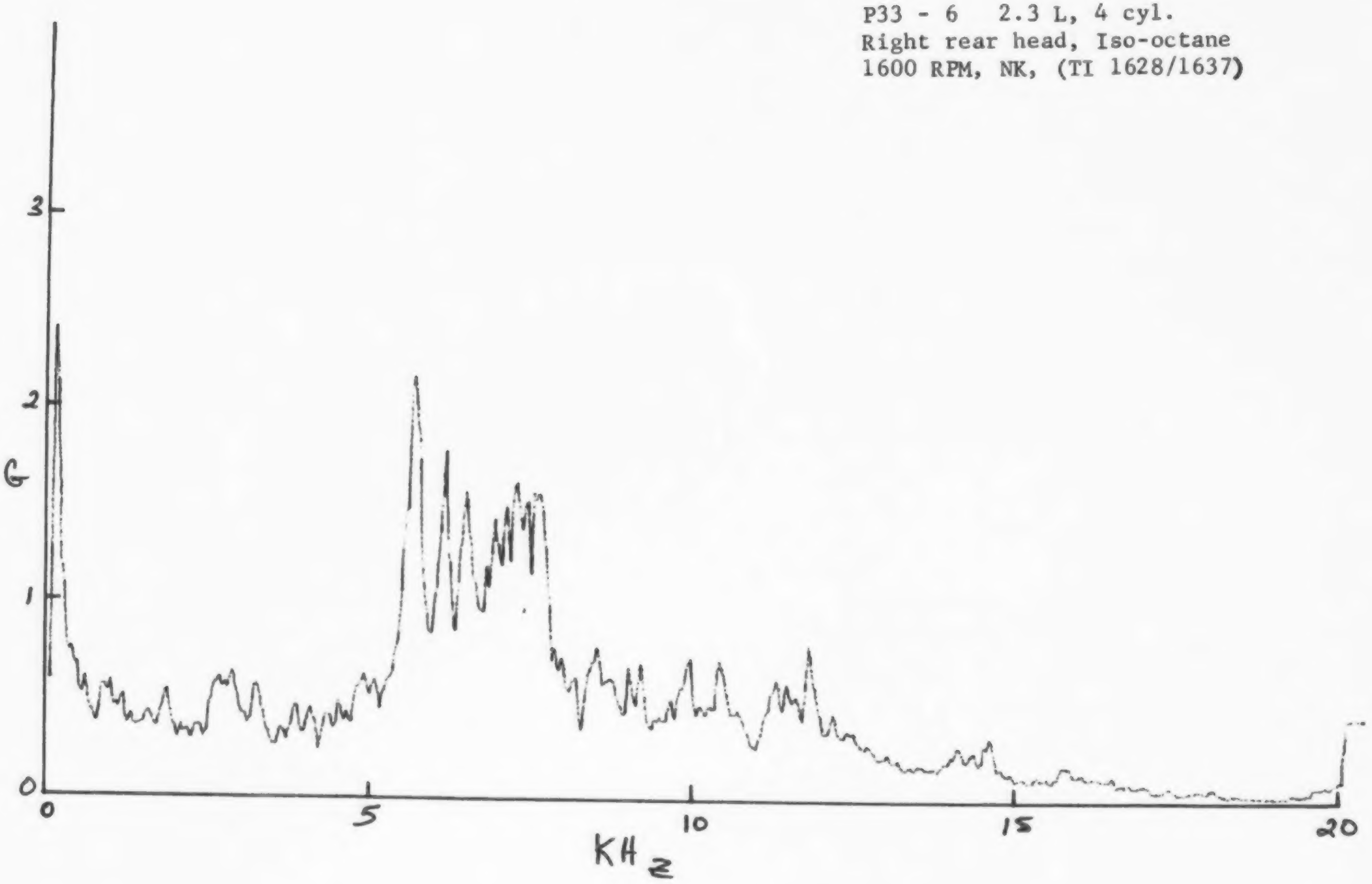
P32 - 7   2.3 L, 4 cyl.
Right front head, Iso-octane
1600 RPM, NK, (TI 1600/1609)

P33-5

P33 - 5   2.3 L, 4 cyl.
Intake Manifold, Iso-octane
1600 RPM, NK, (TI 1628/1637)



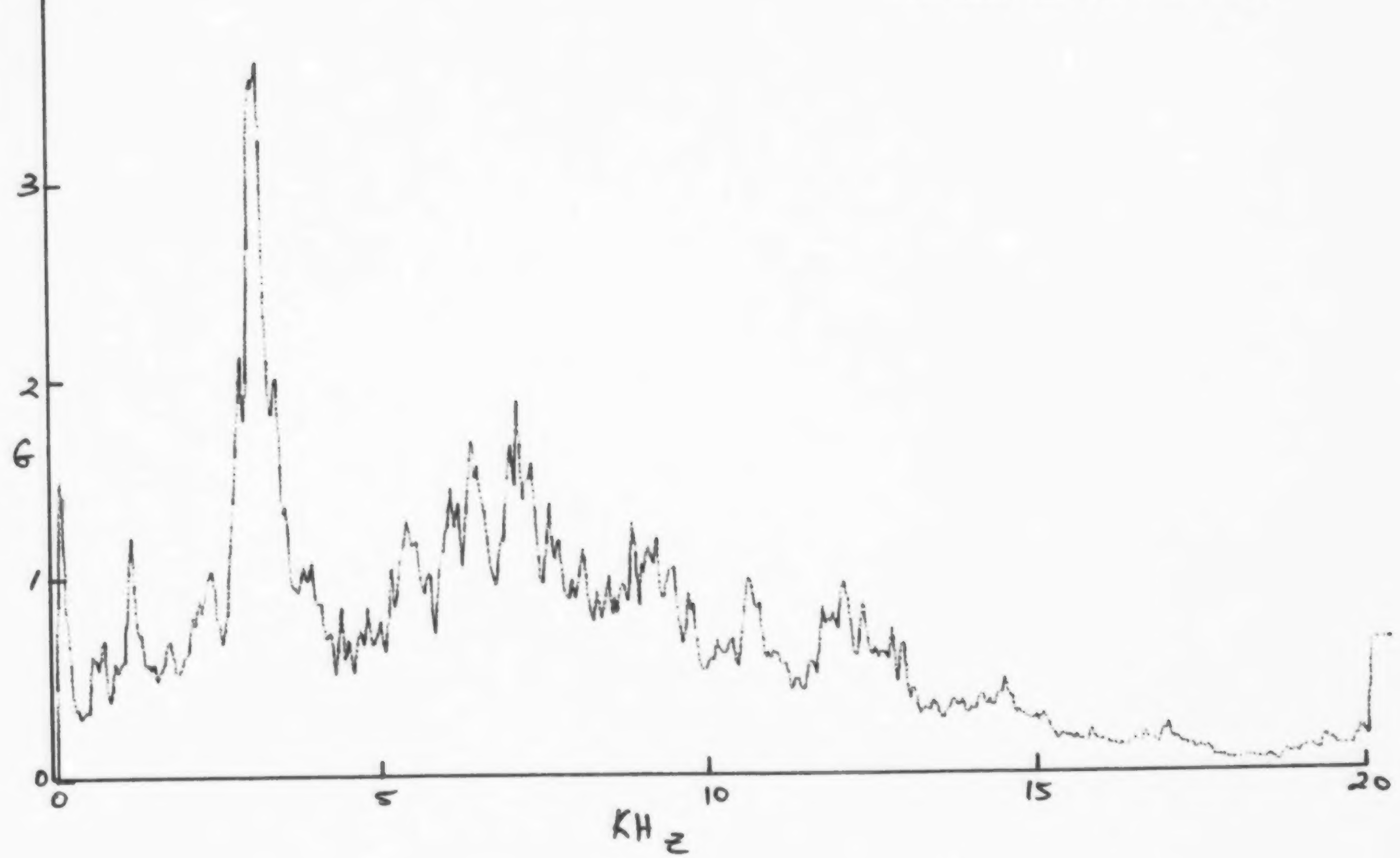
P33-6



P33 - 6 2.3 L, 4 cyl.
Right rear head, Iso-octane
1600 RPM, NK, (TI 1628/1637)

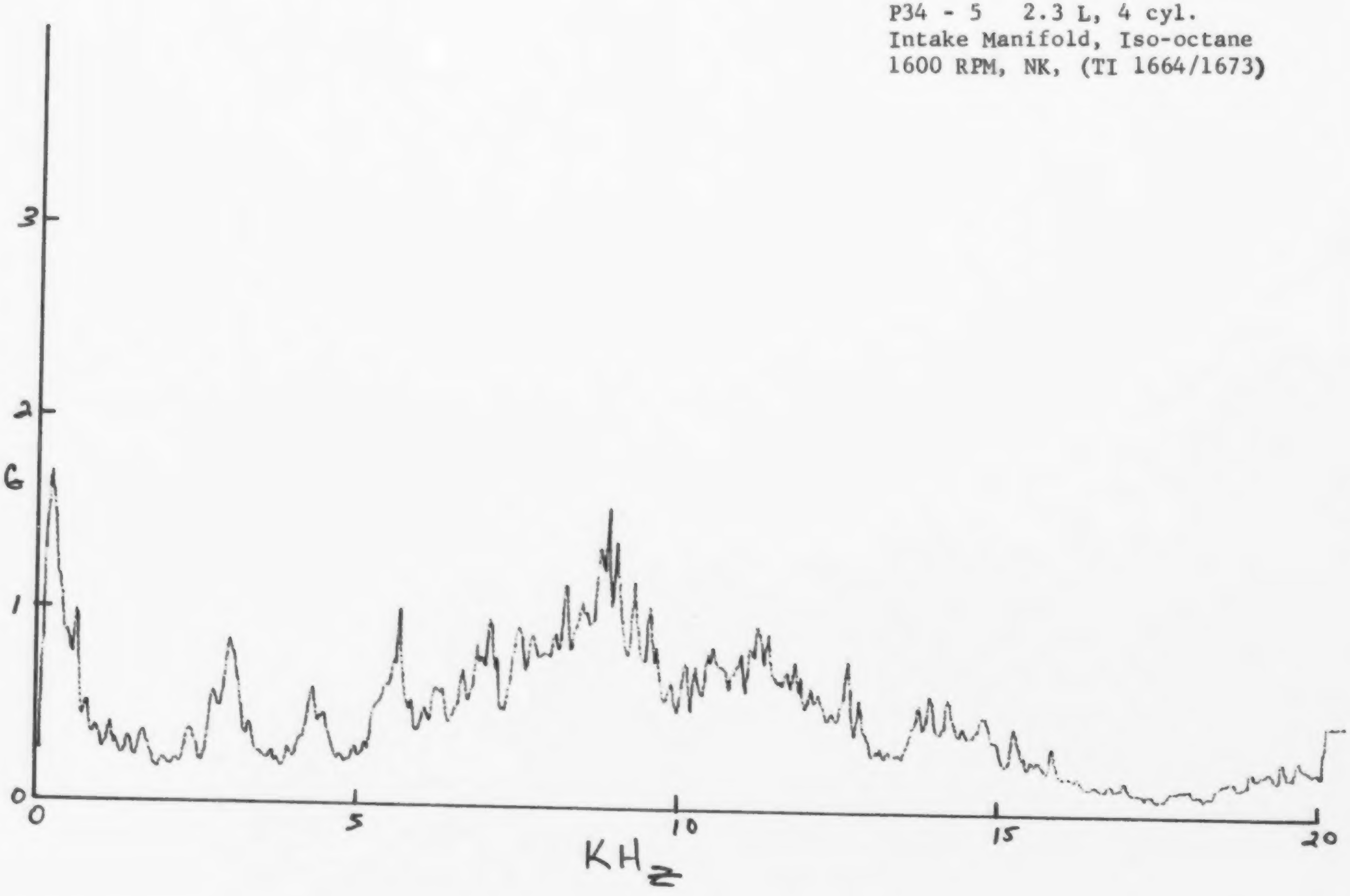
P33-7

P33 - 7 2.3 L, 4 cyl.
Right front block, Iso-octane
1600 RPM, NK, (TI 1628/1637)

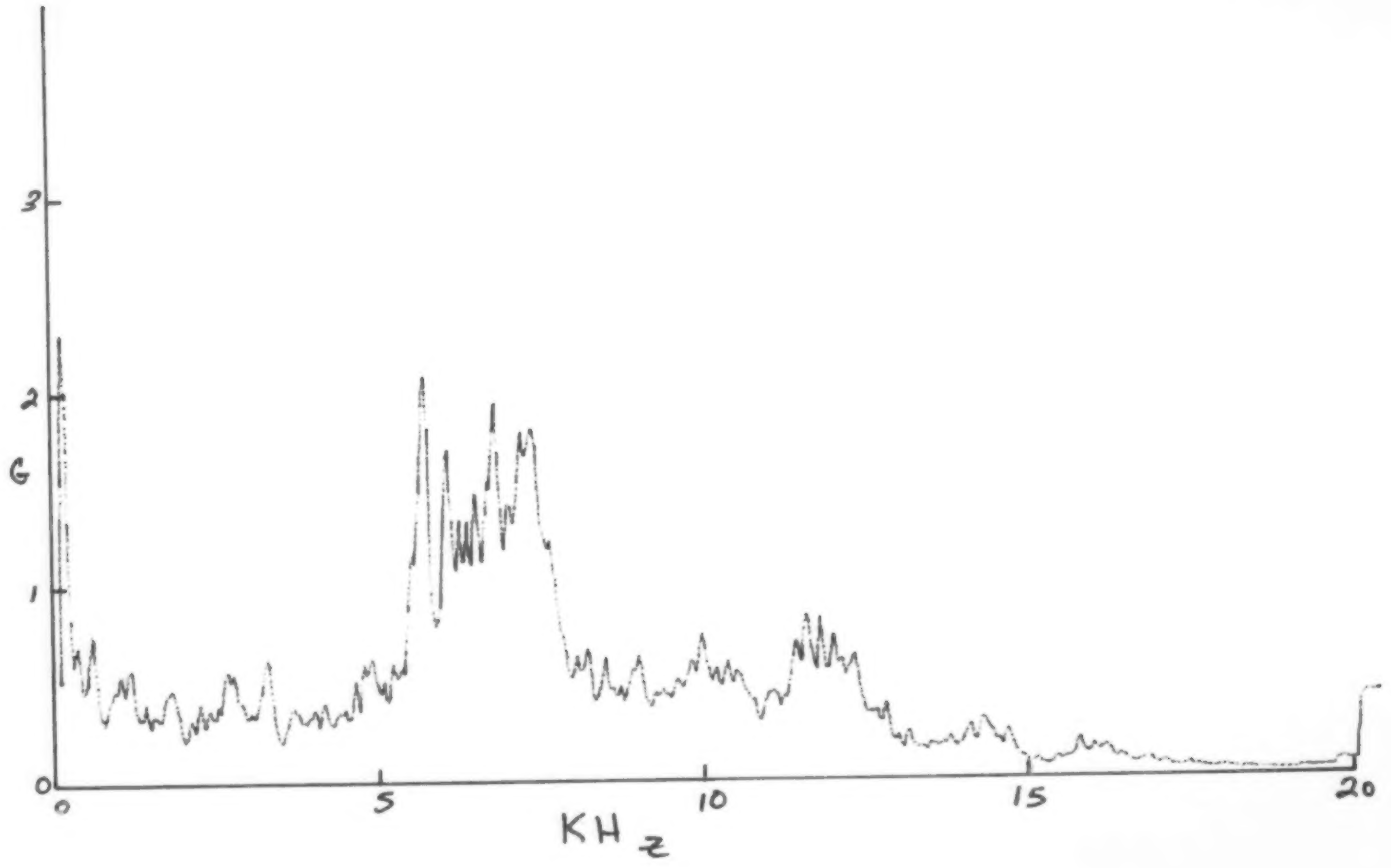


P34-5

P34 - 5   2.3 L, 4 cyl.
Intake Manifold, Iso-octane
1600 RPM, NK, (TI 1664/1673)

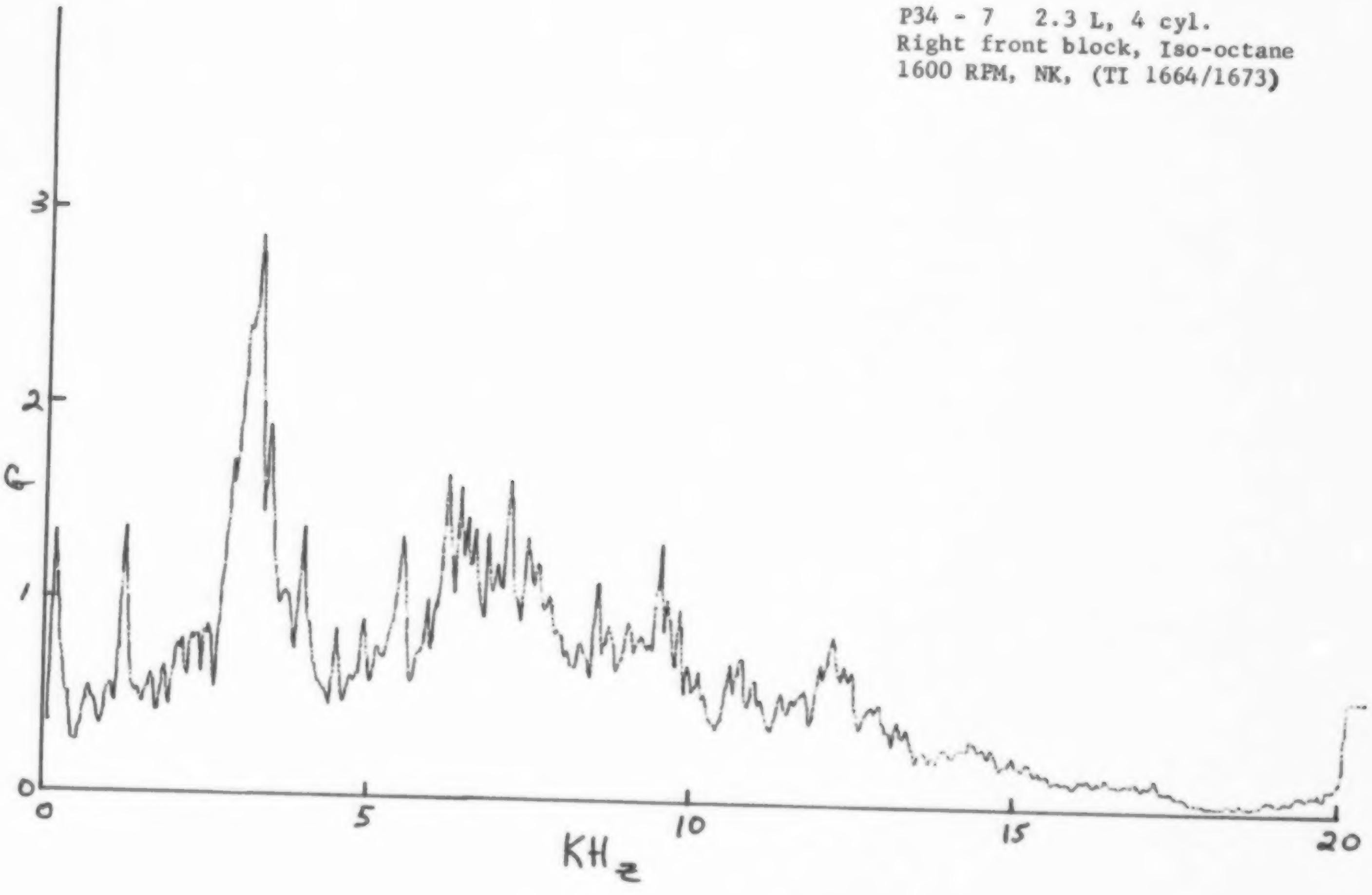


P34-6



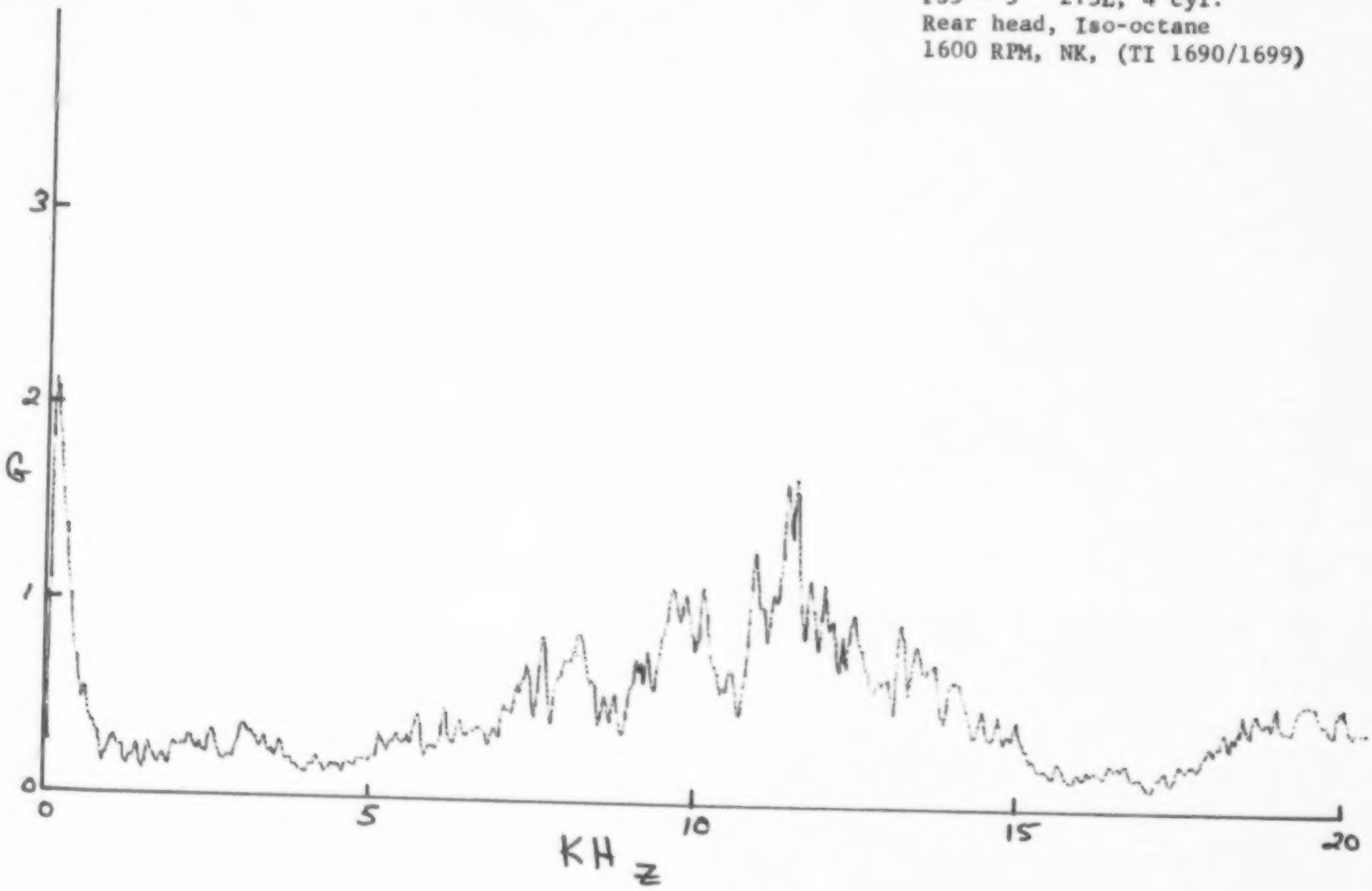
P34 - 6   2.3 L, 4 cyl.
Right rear head, Iso-octane
1600 RPM, NK, (TI 1664/1673)

P34-7



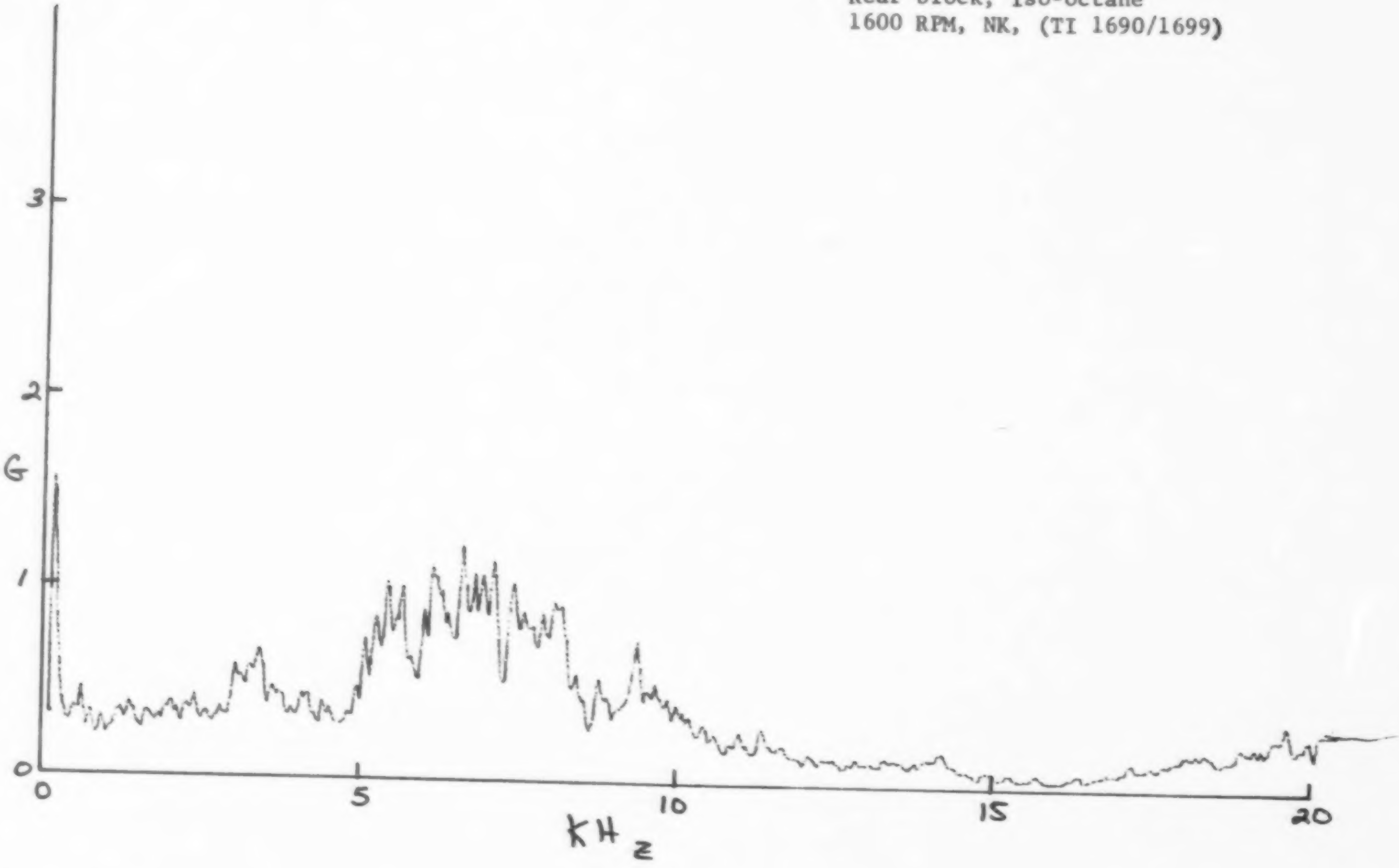
P34 - 7 2.3 L, 4 cyl.
Right front block, Iso-octane
1600 RPM, NK, (TI 1664/1673)

P35-5



P35 - 5   2.3L, 4 cyl.
Rear head, Iso-octane
1600 RPM, NK, (TI 1690/1699)

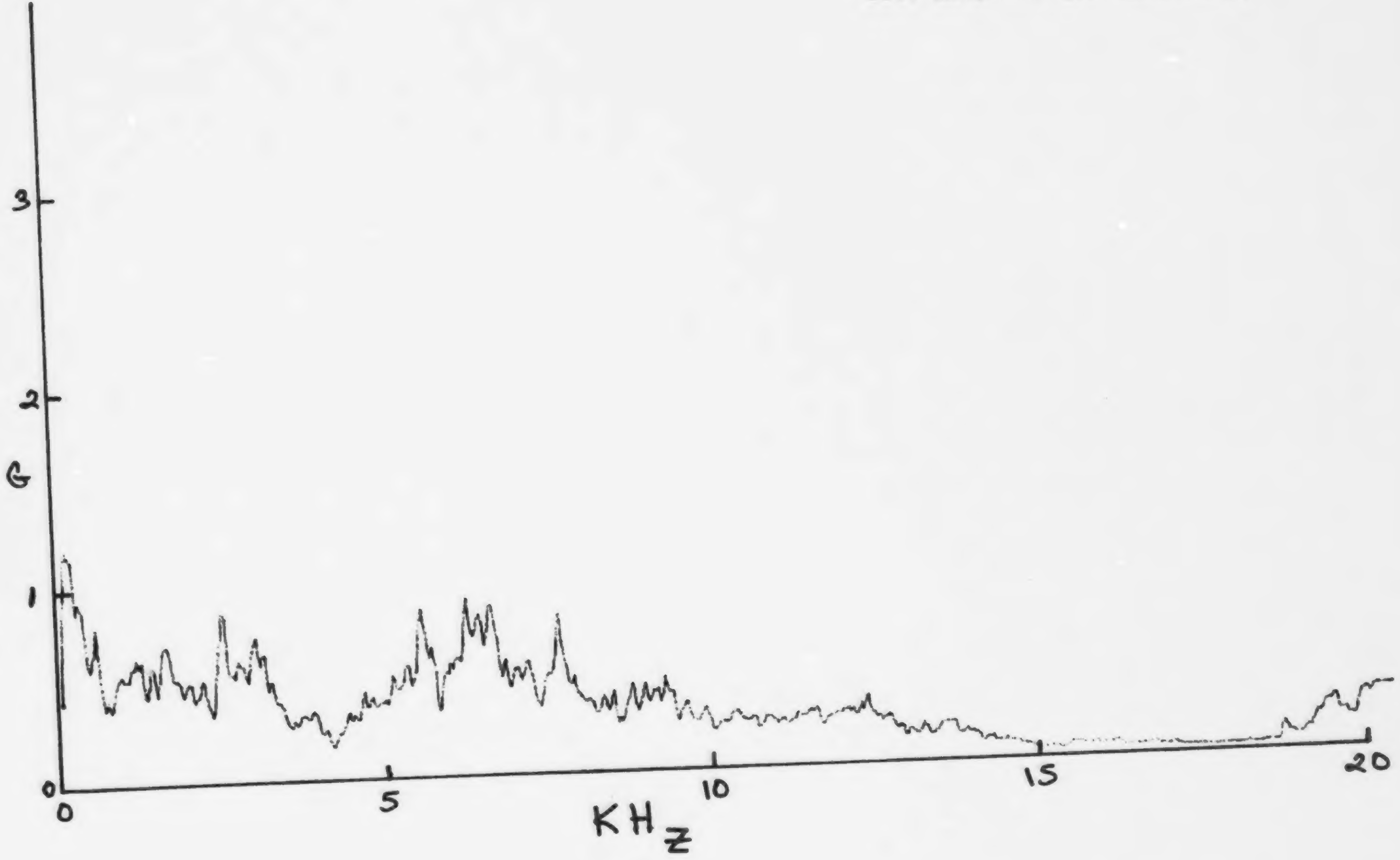
P35-6



P35 - 6   2.3 L, 4 cyl.
Rear block, Iso-octane
1600 RPM, NK, (TI 1690/1699)

P35-7

P35 - 7   2.3 L, 4 cyl.
Right front head, Iso-octane
1600 RPM, NK, (TI 1690/1699)



APPENDIX F - 2

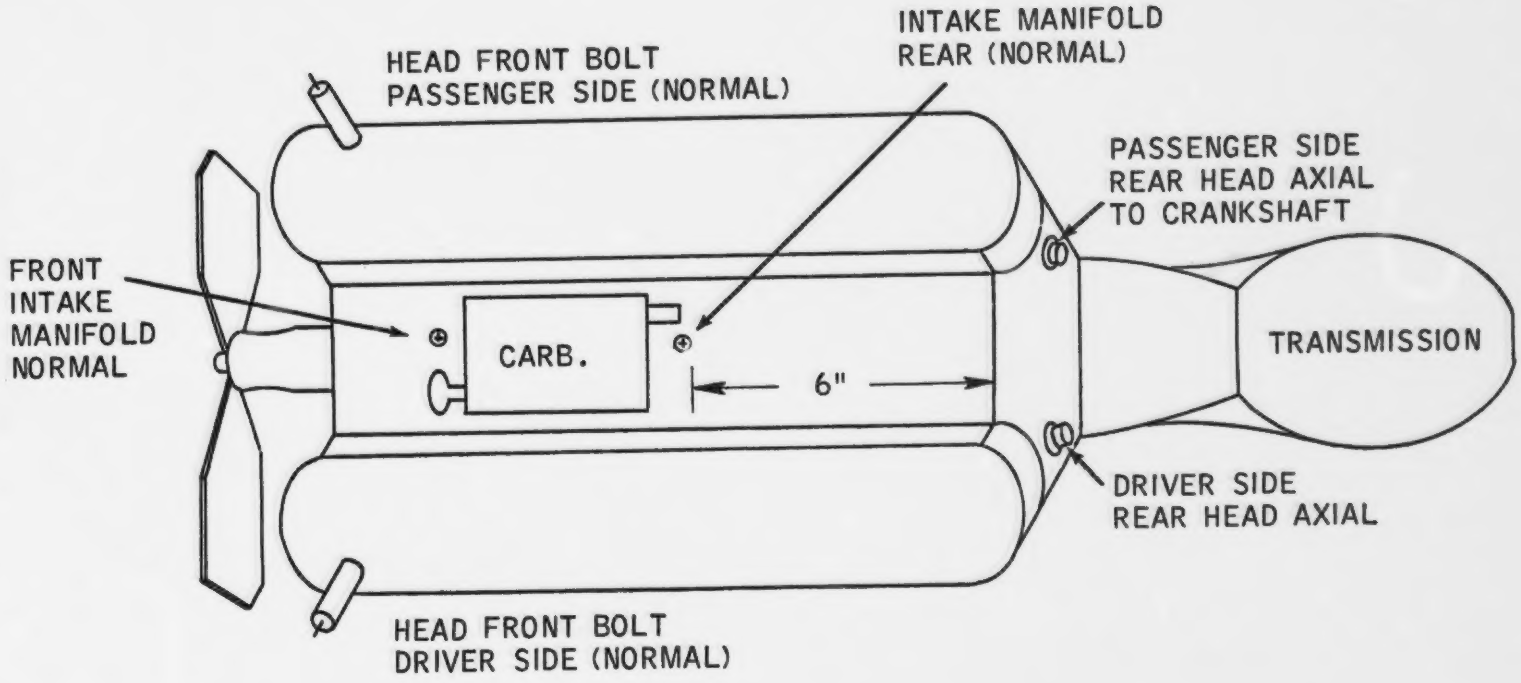
Frequency Analysis Ot 2.8 Liter, Ford V-6 Engine

Run No.	Accelerometer	Speed	Knock Rating
FV 1 - 5	Head front bolt Driver side(normal)	1600 RPM	NK
FV 1 - 6	Passenger side Rear head(axial)	1600 RPM	NK
FV 1 - 7	Head front bolt Passenger side(normal)	1600 RPM	NK
FV 2 - 5	Intake manifold Rear (normal)	2550 RPM	NK
FV 2 - 6	Intake manifold Front (normal)	2550 RPM	NK
FV 2 - 7	Driver side Rear head (axial)	2550 RPM	NK
FV 3 - 5	Head front bolt Driver side (normal)	1600 RPM	T+
FV 3 - 6	Passenger side Rear head (axial)	1600 RPM	T+
FV 3 - 7	Head front bolt Passenger side(normal)	1600 RPM	T+
FV 4 - 5	Intake manifold Rear (normal)	1600 RPM	T+
FV 4 - 6	Intake manifold front (normal)	1600 RPM	T+
FV 4 - 7	Driver side rear head (axial)	1600 RPM	T+
FV 5 - 5	Intake Manifold rear (normal)	1600 RPM	T-
FV 5 - 6	Intake Manifold front (normal)	1600 RPM	T-
FV 5 - 7	Driver side rear head (axial)	1600 RPM	T-
FV 6 - 5	Head front bolt Driver side (normal)	1600 RPM	T-
FV 6 - 6	Passenger side Rear head (axial)	1600 RPM	T-
FV 6 - 7	Head front bolt Passenger side(normal)	1600 RPM	T-

Run No.	Accelerometer	Speed	Knock Rating
FV 7 - 5	Head front bolt Driver side (normal)	2550 RPM	T+
FV 7 - 6	Passenger side Rear head (axial)	2550 RPM	T+
FV 7 - 7	Head front bolt Passenger side(normal)	2550 RPM	T+
FV 8 - 5	Intake manifold Rear (normal)	2560 RPM	T+
FV 8 - 6	Intake manifold Front (normal)	2560 RPM	T+
FV 8 - 7	Driver side Rear head (axial)	2560 RPM	T+
FV 9 - 5	Intake manifold rear (normal)	2555 RPM	T-
FV 9 - 6	Intake manifold Front (normal)	2555 RPM	T-
FV 9 - 7	Driver side Rear head (axial)	2555 RPM	T-
FV 10 - 5	Head front bolt Driver side (normal)	2555 RPM	T-
FV 10 - 6	Passenger side Rear head (axial)	2555 RPM	T-
FV 10 - 7	Head front bolt Passenger side(normal)	2555 RPM	T-
FV 11 - 5	Head front bolt Driver side (normal)	40-70 MPH Accel.	NK
FV 11 - 6	Passenger side Rear head (axial)	40-70 MPH Accel.	NK
FV 11 - 7	Head front bolt Passenger side(normal)	40-70 MPH Accel.	NK
FV 12 - 5	Intake manifold Rear (normal)	40-70 MPH Accel.	NK
FV 12 - 6	Intake manifold Front (normal)	40-70 MPH Accel.	NK
FV 12 - 7	Driver side Rear head (axial)	40-70 MPH Accel.	NK
FV 13 - 5	Intake manifold rear (normal)	40-70 MPH Accel.	Heavy Knock
FV 13 - 6	Intake manifold Front (normal)	40-70 MPH Accel.	Heavy Knock

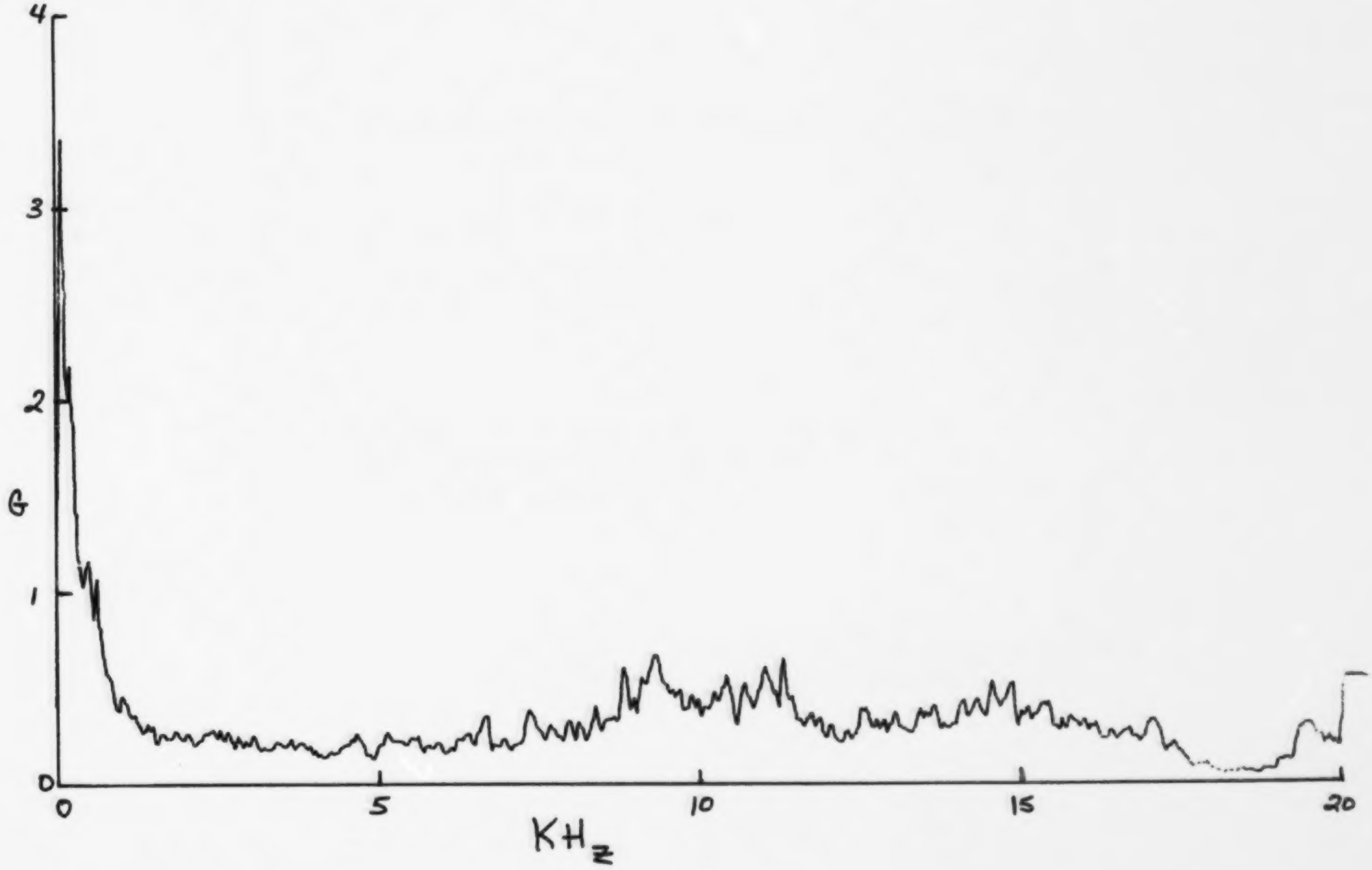
Run No.	Accelerometer	Speed	Knock Rating
FV 14 - 5	Intake manifold Rear (normal)	40-70 MPH Accel.	VL+
FV 14 - 6	Intake manifold Front (normal)	40-70 MPH Accel.	VL+
FV 14 - 7	Driver side rear head (axial)	40-70 MPH Accel.	VL+
FV 15 - 5	Head front bolt Driver side (normal)	40-70 MPH Accel.	VL+
FV 15 - 6	Passenger side Rear head (axial)	40-70 MPH Accel.	VL+
FV 15 - 7	Head front bolt Passenger side(normal)	40-70 MPH Accel.	VL+

LOCATION OF ACCELEROMETERS ON
FORD 2.8 LITER V6 ENGINE (TOP VIEW)


HEAD FRONT BOLT
PASSENGER SIDE (NORMAL)
INTAKE MANIFOLD
REAR (NORMAL)
PASSENGER SIDE
REAR HEAD AXIAL
TO CRANKSHAFT
FRONT
INTAKE
MANIFOLD
NORMAL
CARB.
6"
TRANSMISSION
DRIVER SIDE
REAR HEAD AXIAL
HEAD FRONT BOLT
DRIVER SIDE (NORMAL)

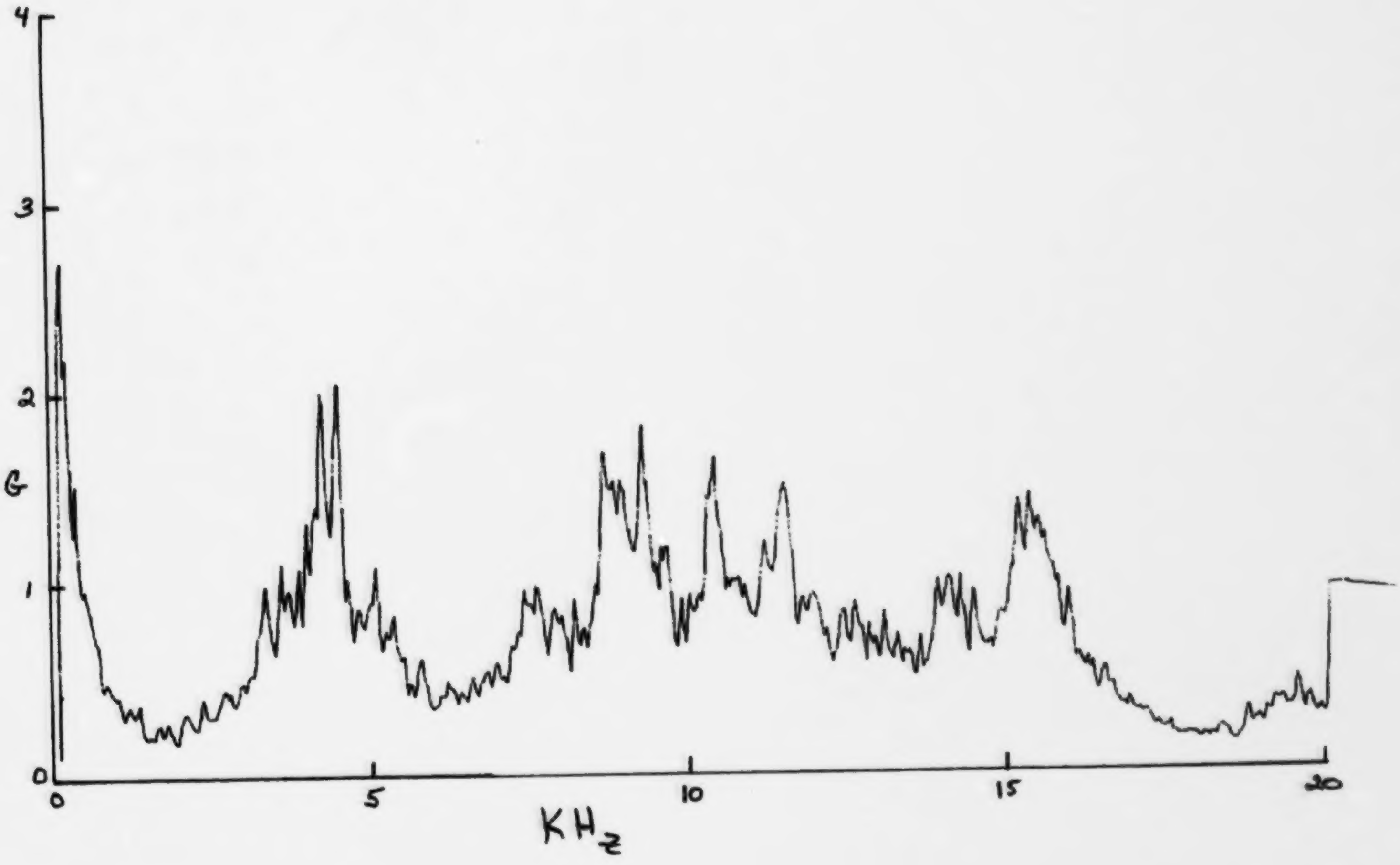
FV1-5

FV1 - 5 2.8 L, Ford V-6
Head front bolt driver side (normal)
Iso-octane, 1600 RPM, NK,
(TI 270/288)



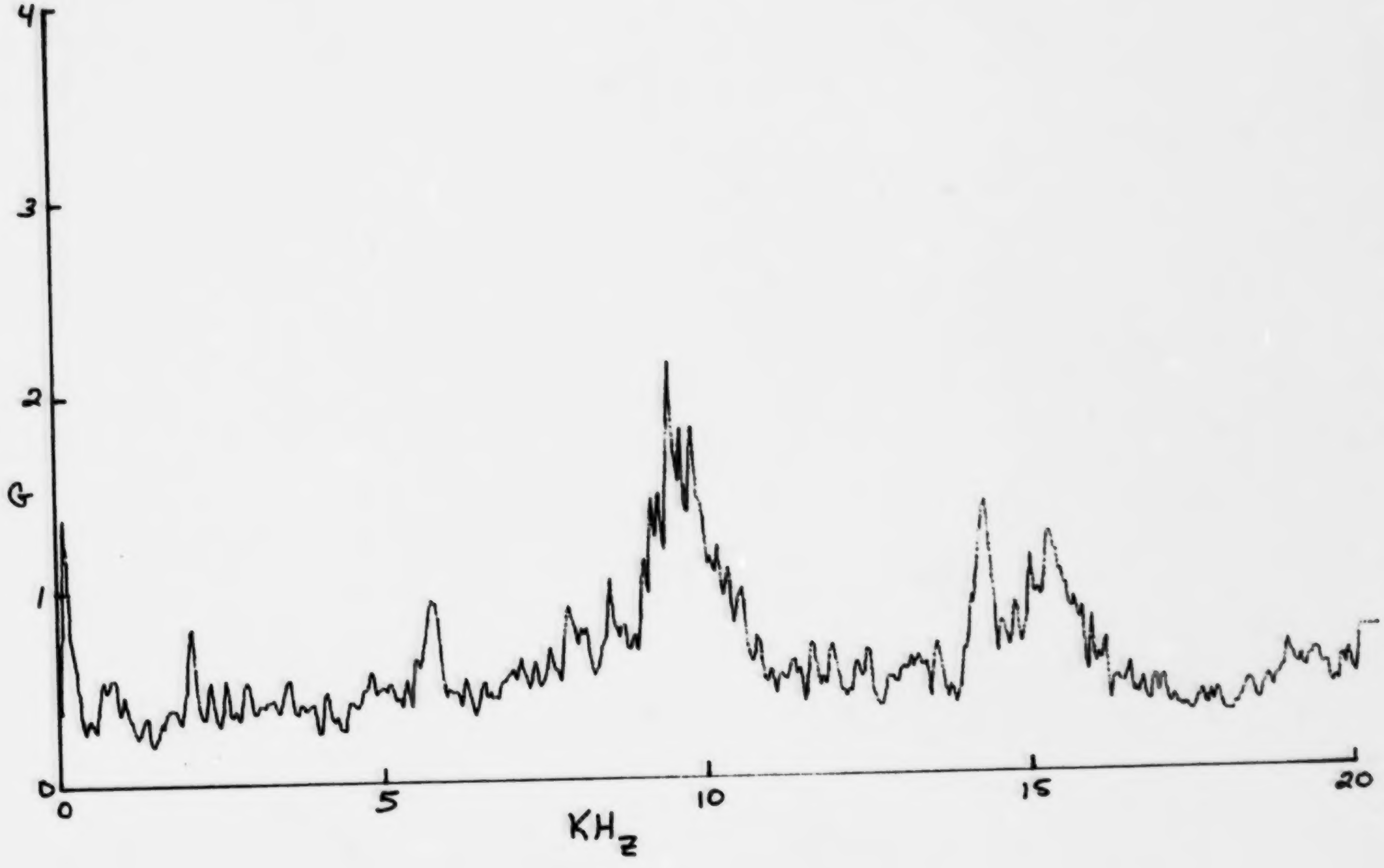
FV1-6

FV1 - 6 2.8 L, Ford V-6
Passenger side rear head (axial)
Iso-octane, 1600 RPM, NK
(TI 270/288)



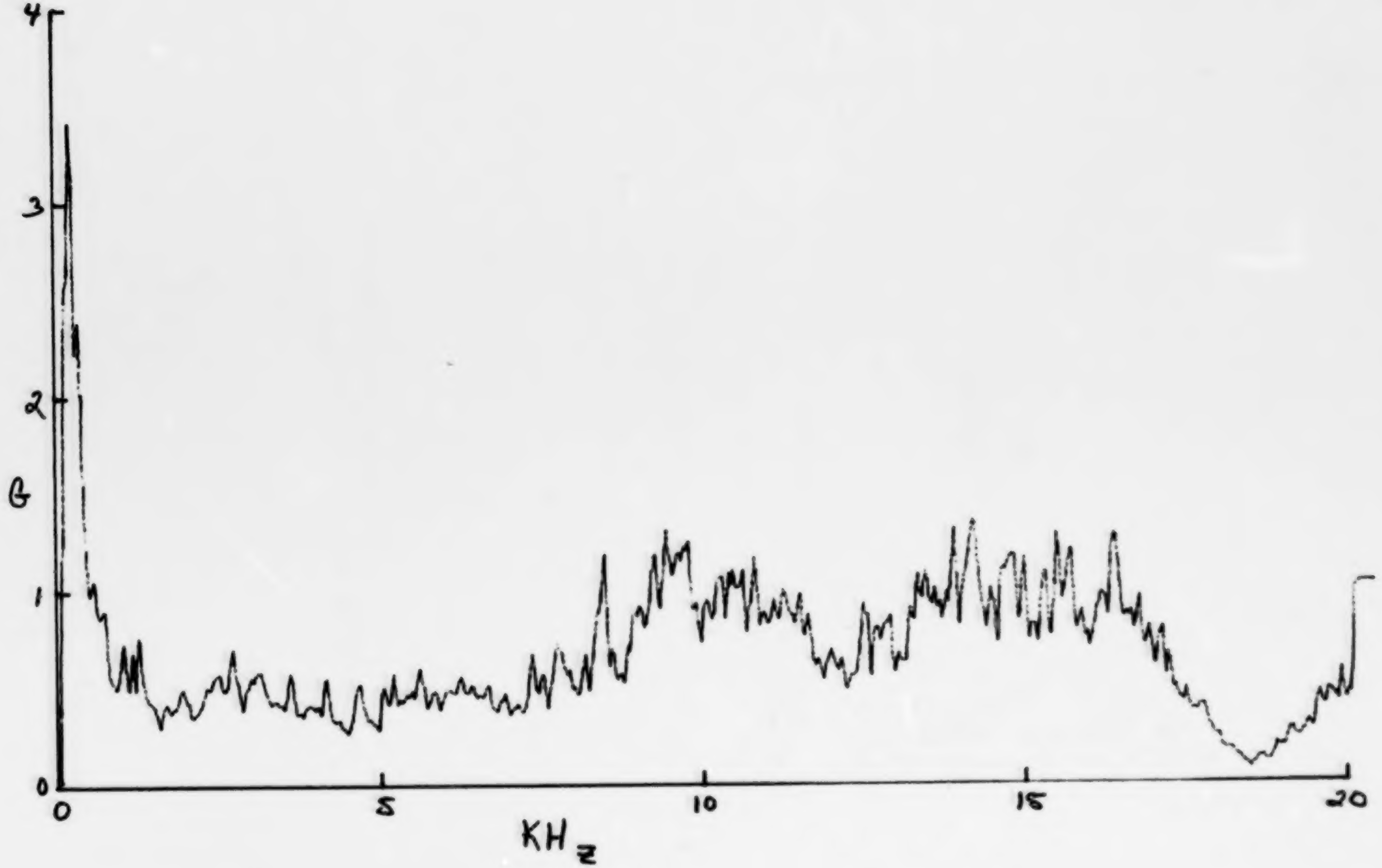
FV1-7

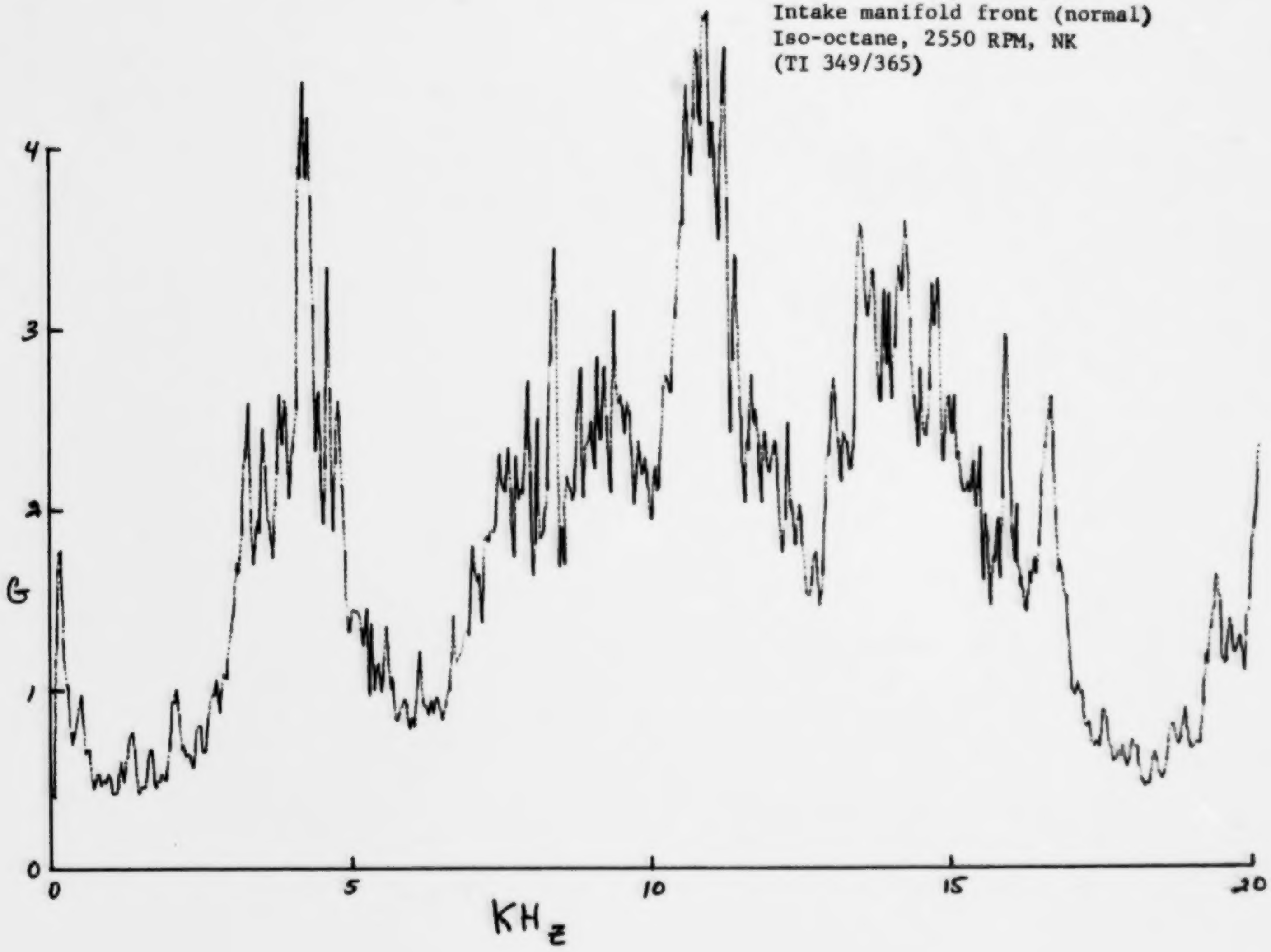
FV1 - 7   2.8 L, Ford V-6
Head front bolt passenger side(normal)
Iso-octane, 1600 RPM, NK
(TI 270/288)



FV2-5

FV2 - 5 2.8 L, Ford V-6
Intake manifold rear (normal)
Iso-octane, 2550 RPM, NK
(TI 349/365)

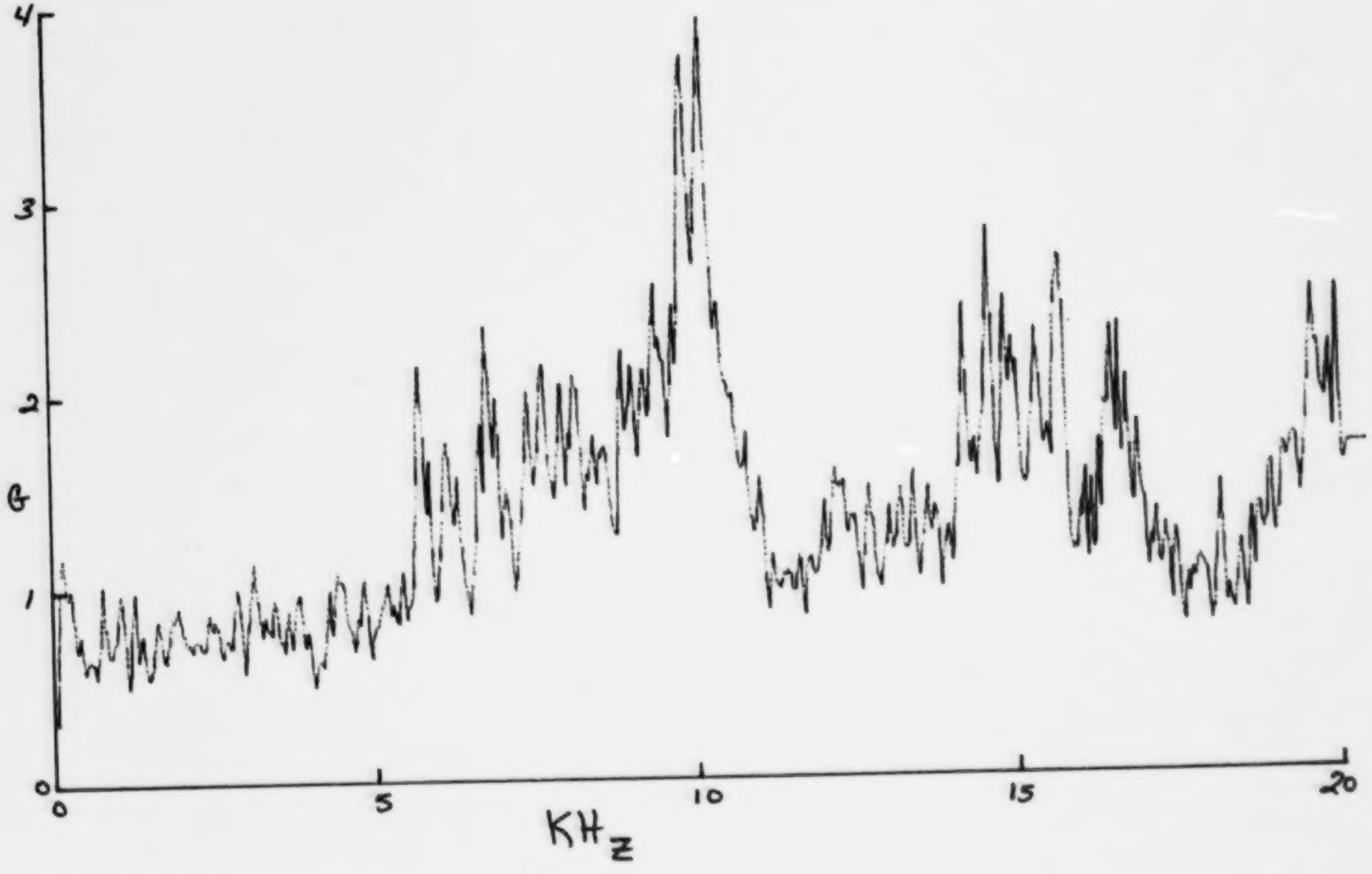




FV2 - 6 2.8 L, Ford V-6
Intake manifold front (normal)
Iso-octane, 2550 RPM, NK
(TI 349/365)

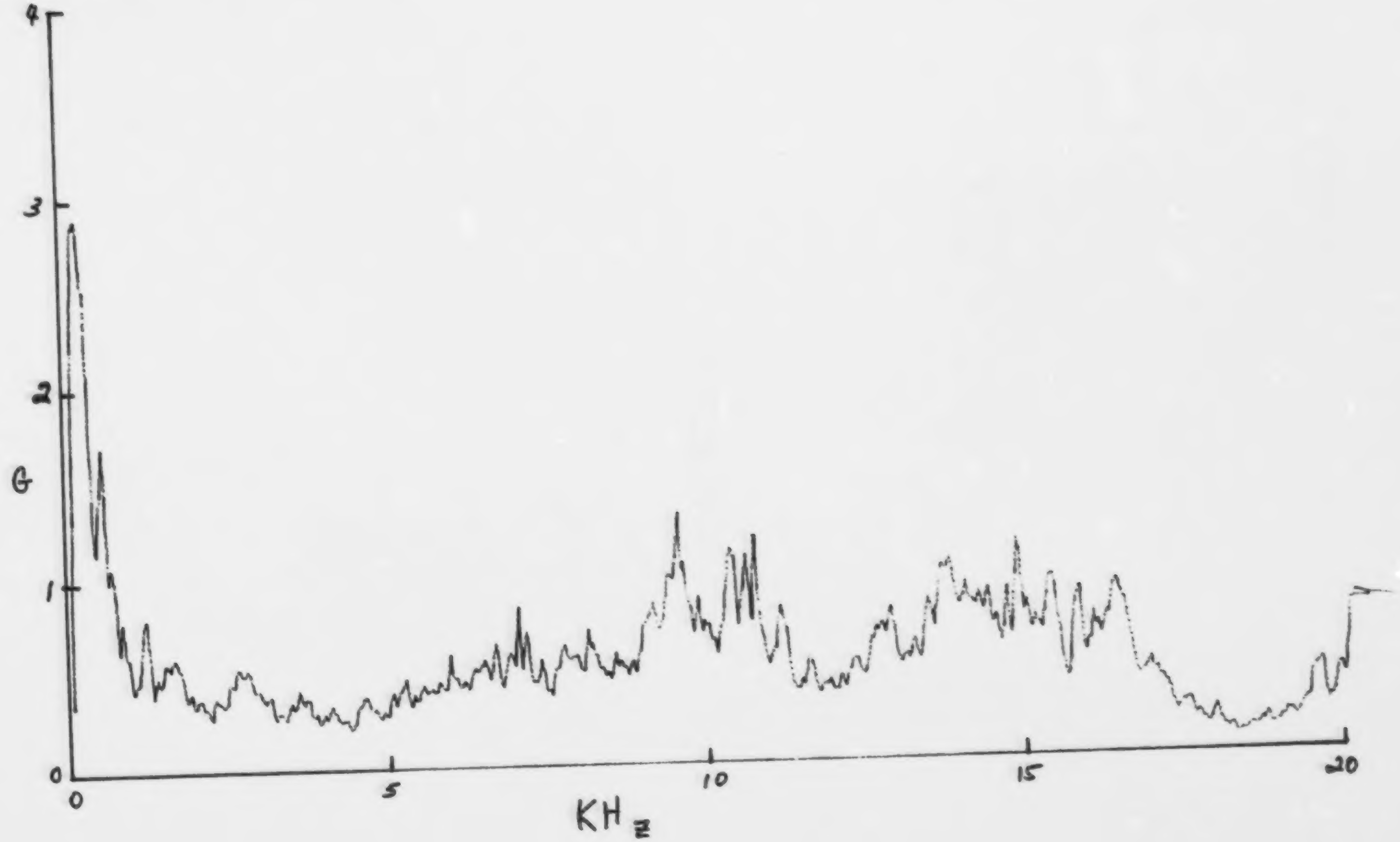
FV2-7

FV2 - 7   2.8 L, Ford V-6
Driver side rear head (axial)
Iso-octane, 2550 RPM, NK
(TI 349/365)



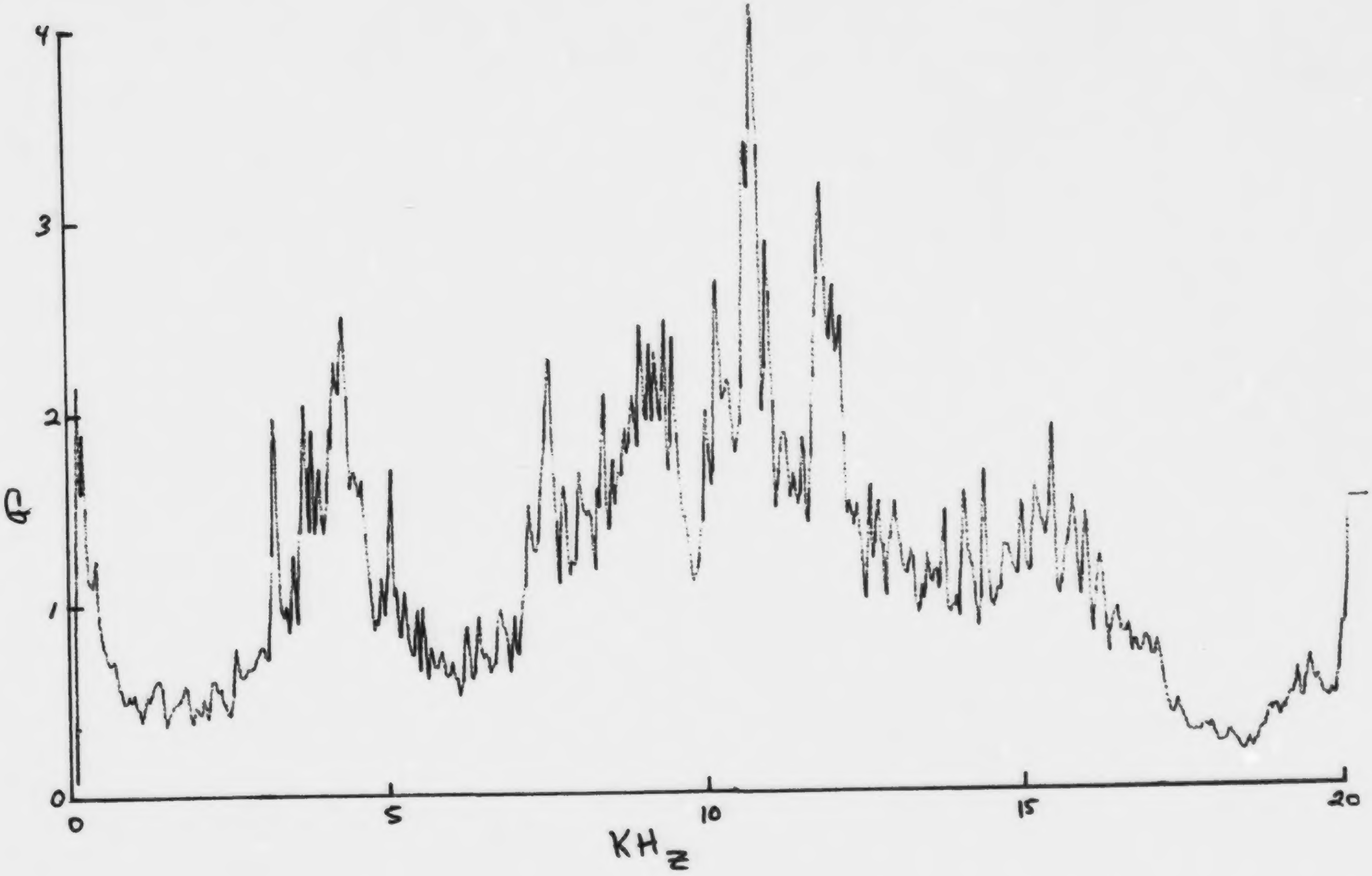
FV3-5

FV3 - 5 2.8 L, Ford V-6
Head front bolt driver side (normal)
C-85, 1600 RPM, T+
(TI 412/429)



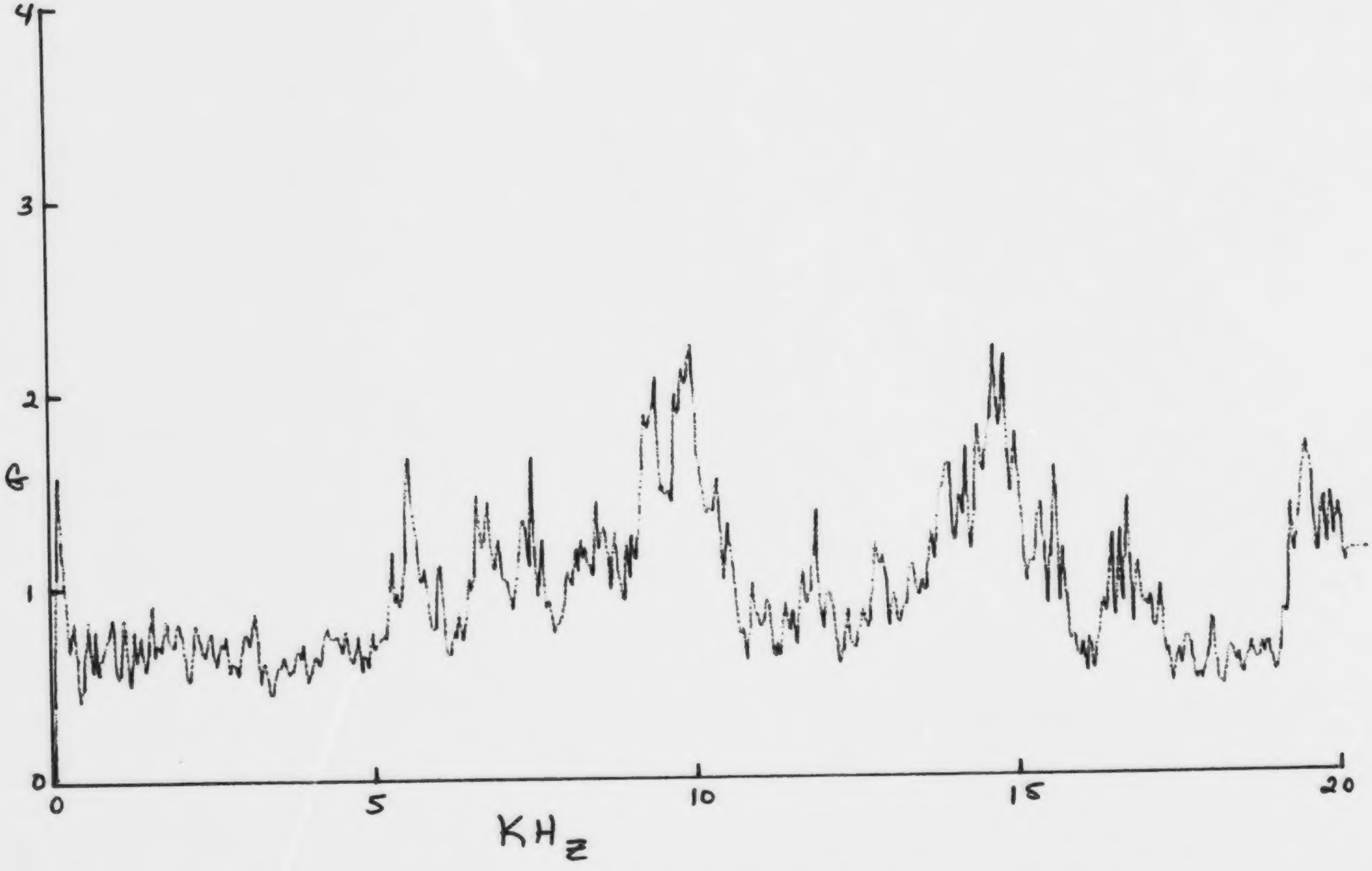
FV3-6

FV3 - 6   2.8 L, Ford V-6
Passenger side rear head (axial)
C-85, 1600 RPM, T+
(TI 412/429)

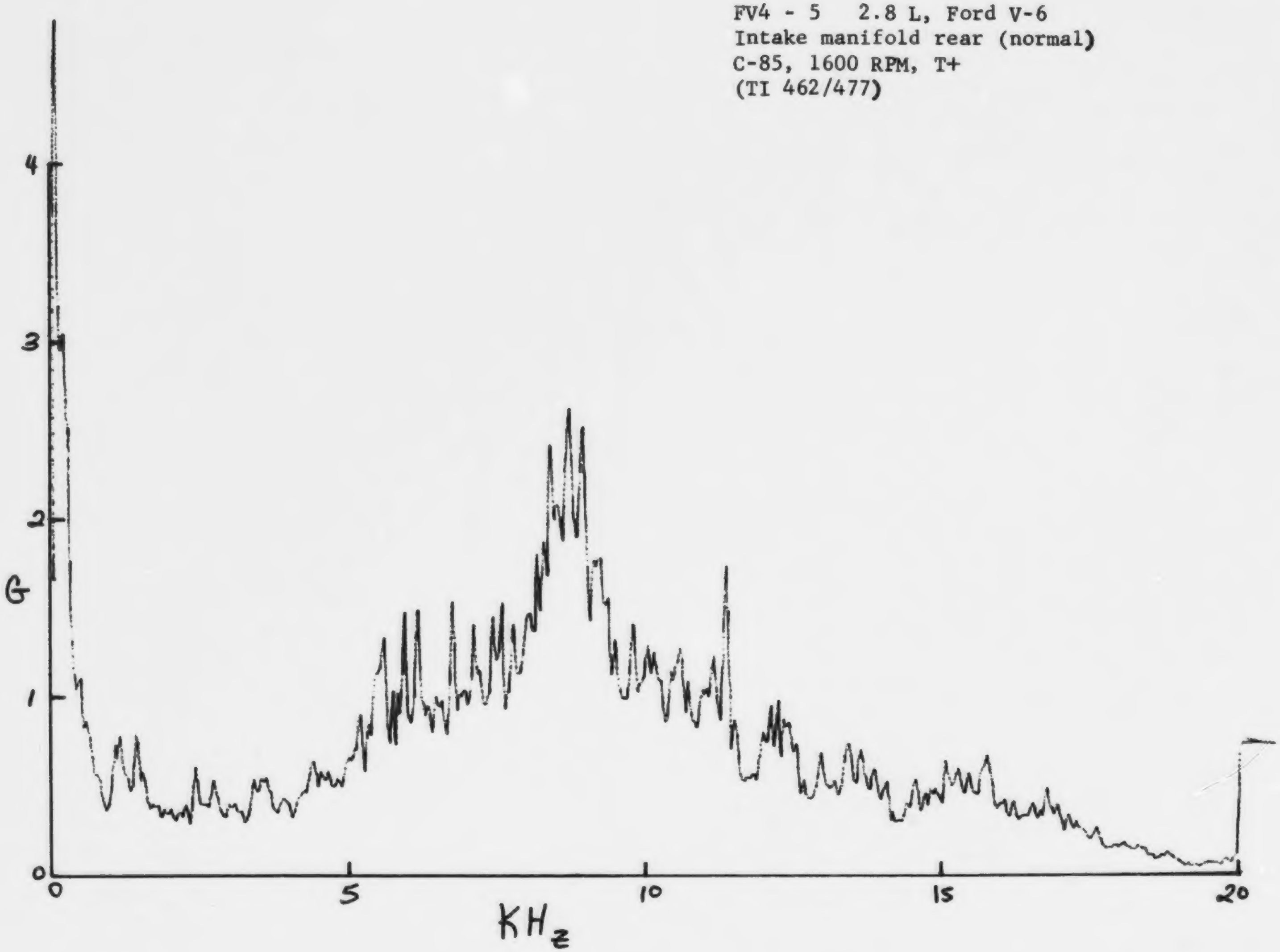


FV3-7

FV3 - 7   2.8 L, Ford V-6
Head front bolt passenger side(normal)
C-85, 1600 RPM, T+
(TI 412/429)



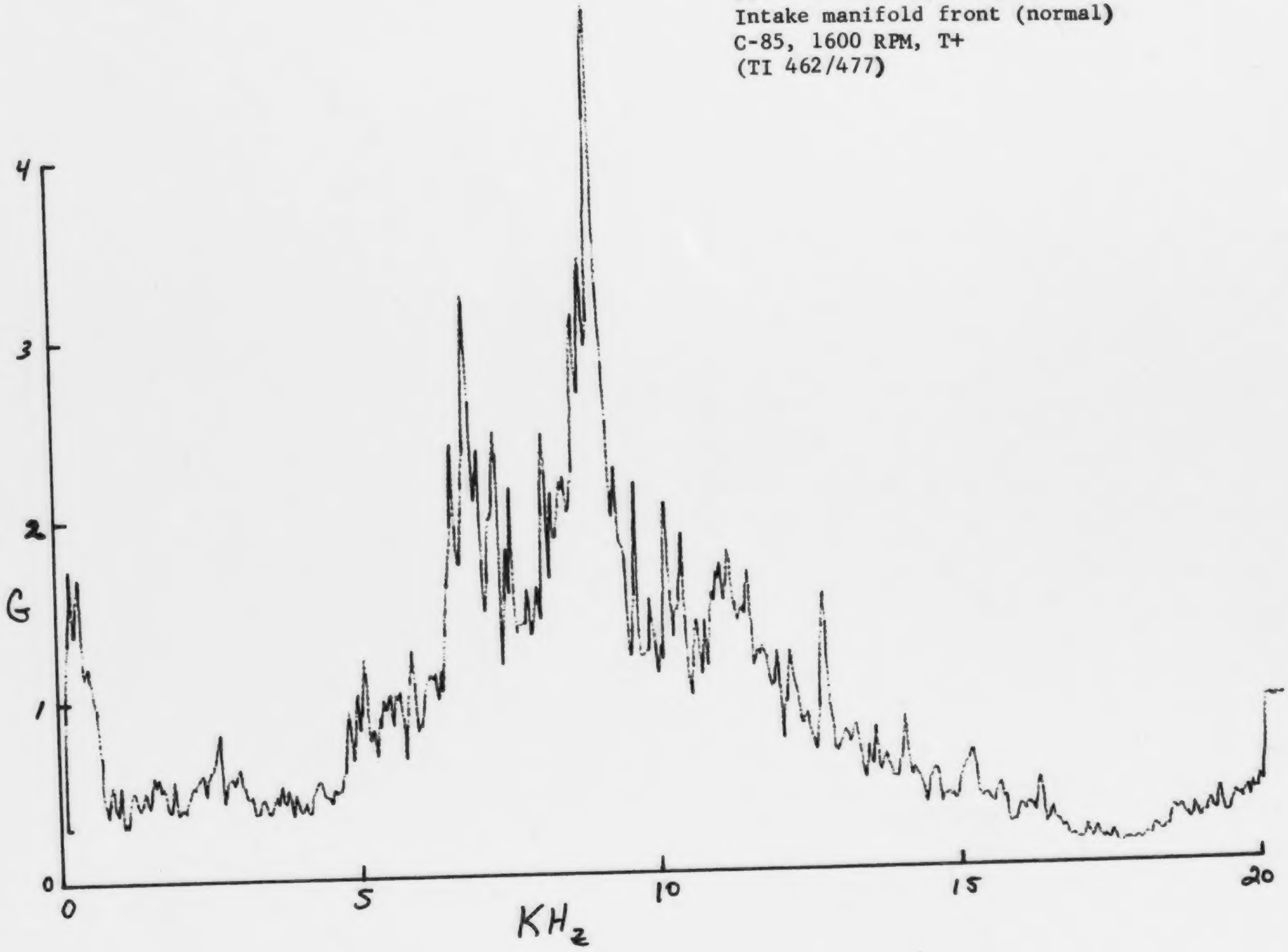
FV4-5



FV4 - 5   2.8 L, Ford V-6
Intake manifold rear (normal)
C-85, 1600 RPM, T+
(TI 462/477)

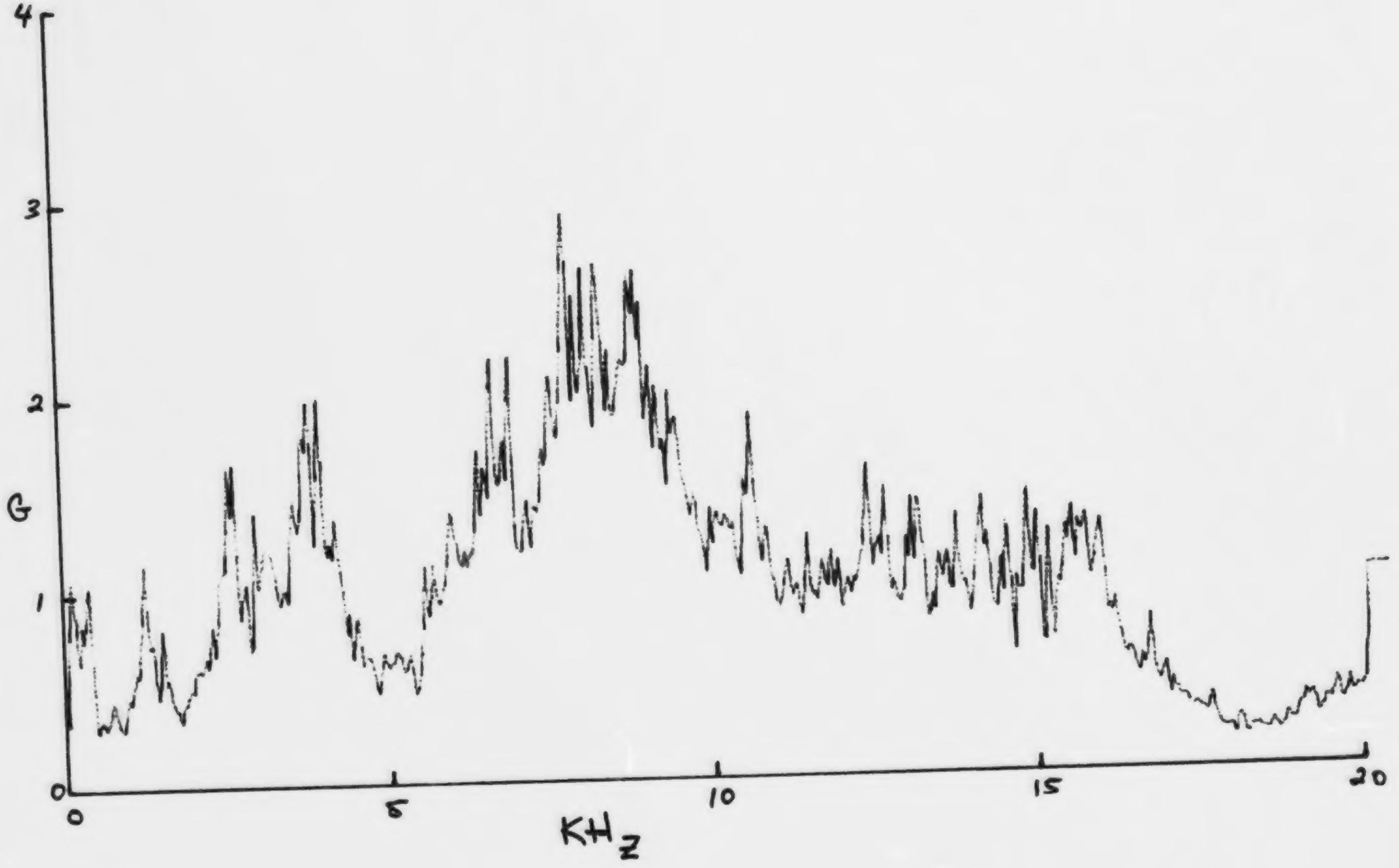
FV4-6

FV4 - 6   2.8 L, Ford V-6
Intake manifold front (normal)
C-85, 1600 RPM, T+
(TI 462/477)



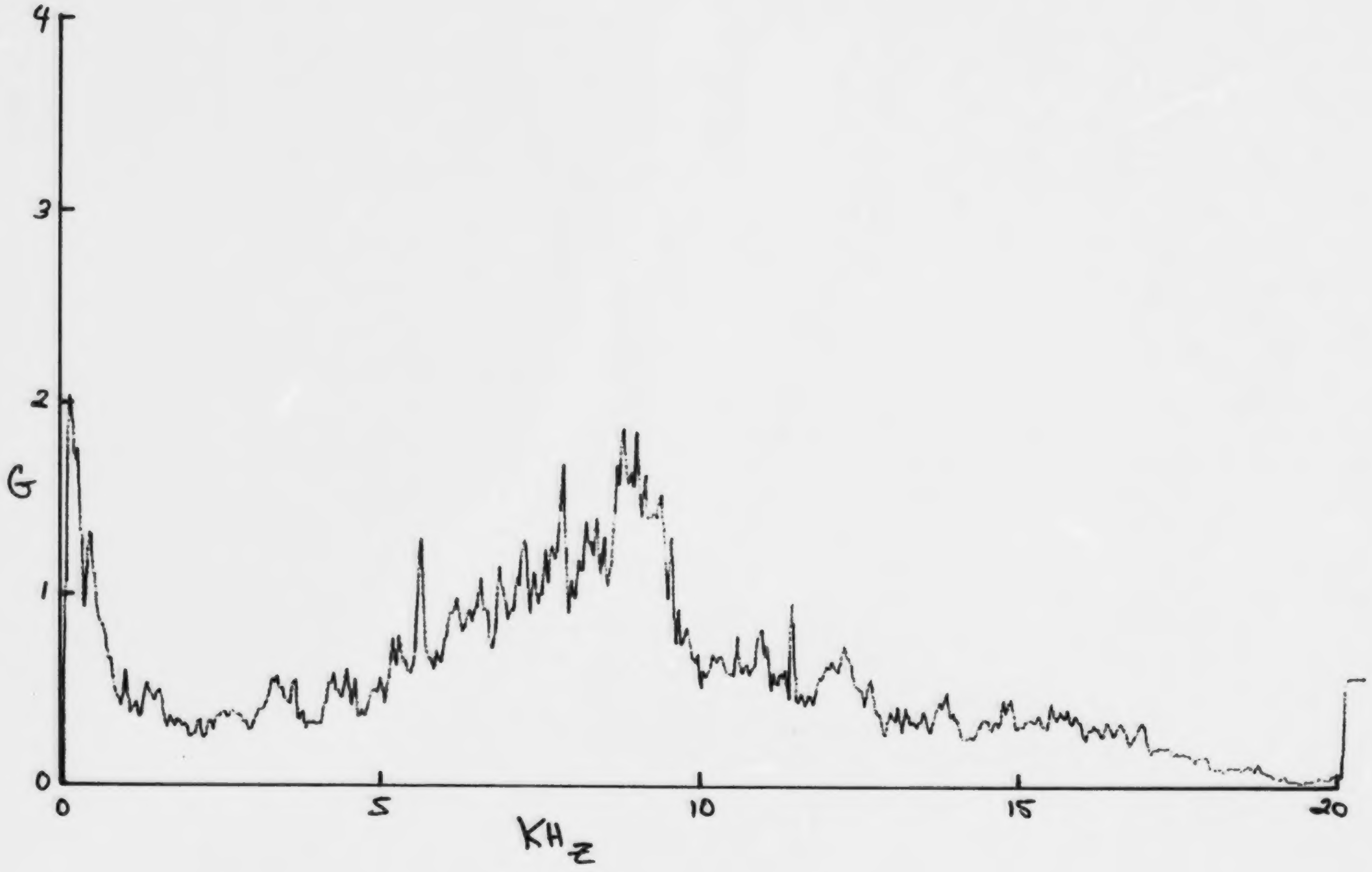
FV4-7

FV4 - 7   2.8 L, Ford V-6
Driver side rear head (axial)
C-85, 1600 RPM, T+
(TI 462/477)



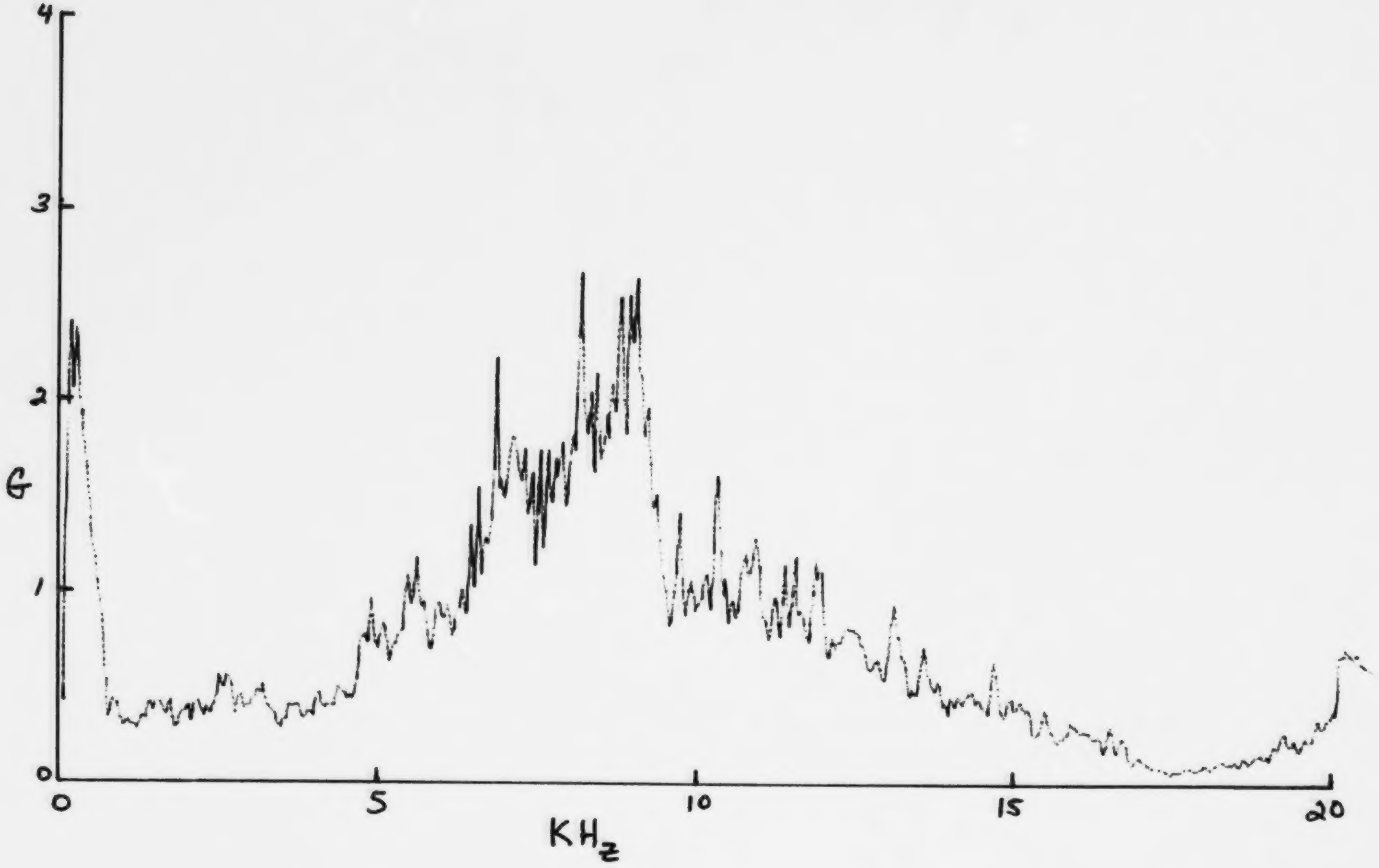
FV5-5

FV5 - 5 2.8 L, Ford V-6
Intake manifold rear (normal)
C-85, 1600 RPM, T-
(TI 502/518)



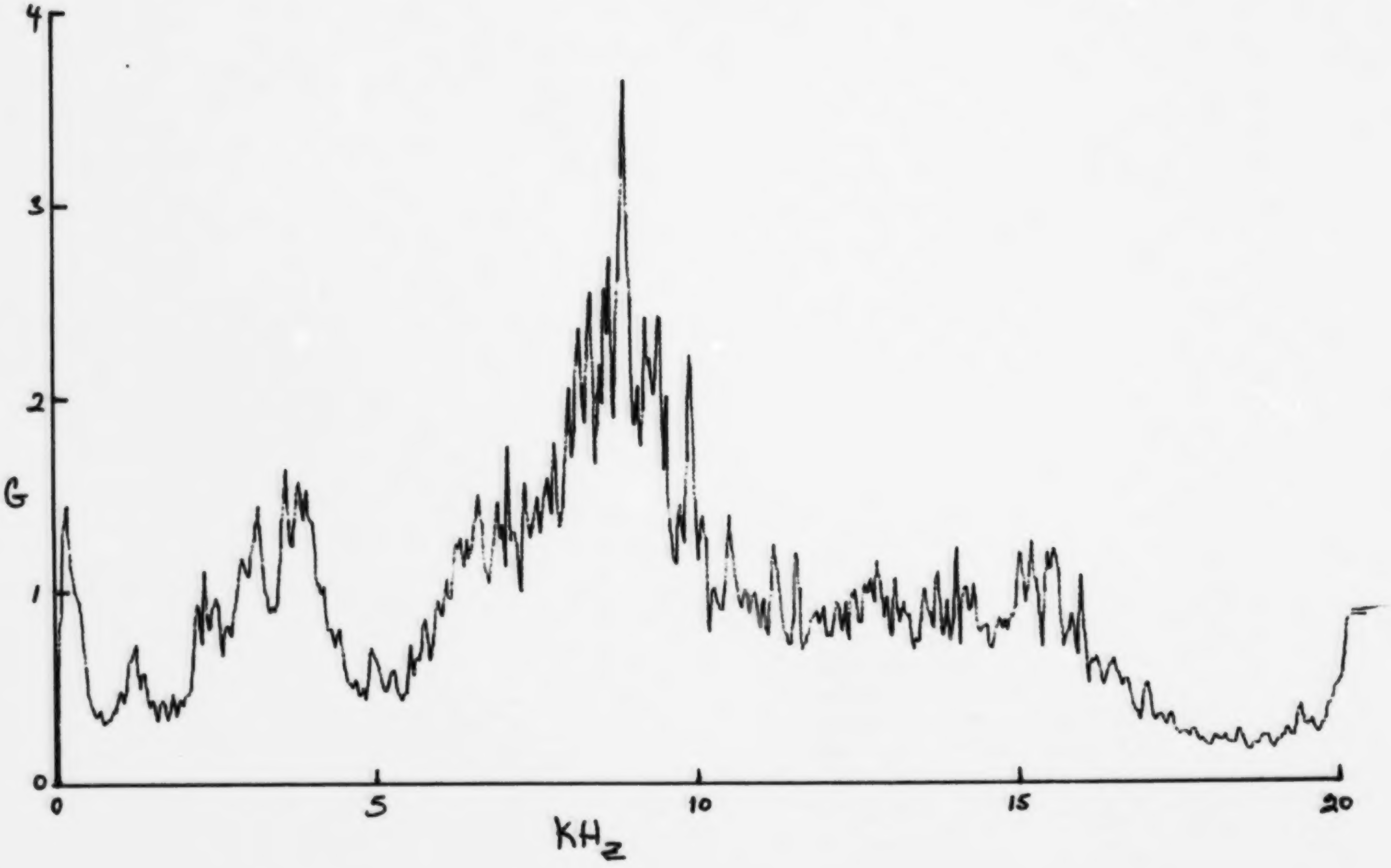
FV5-6

FV5 - 6 2.8 L, Ford V-6
Intake manifold front (normal)
C-85, 1600 RPM, T-
(TI 502/518)



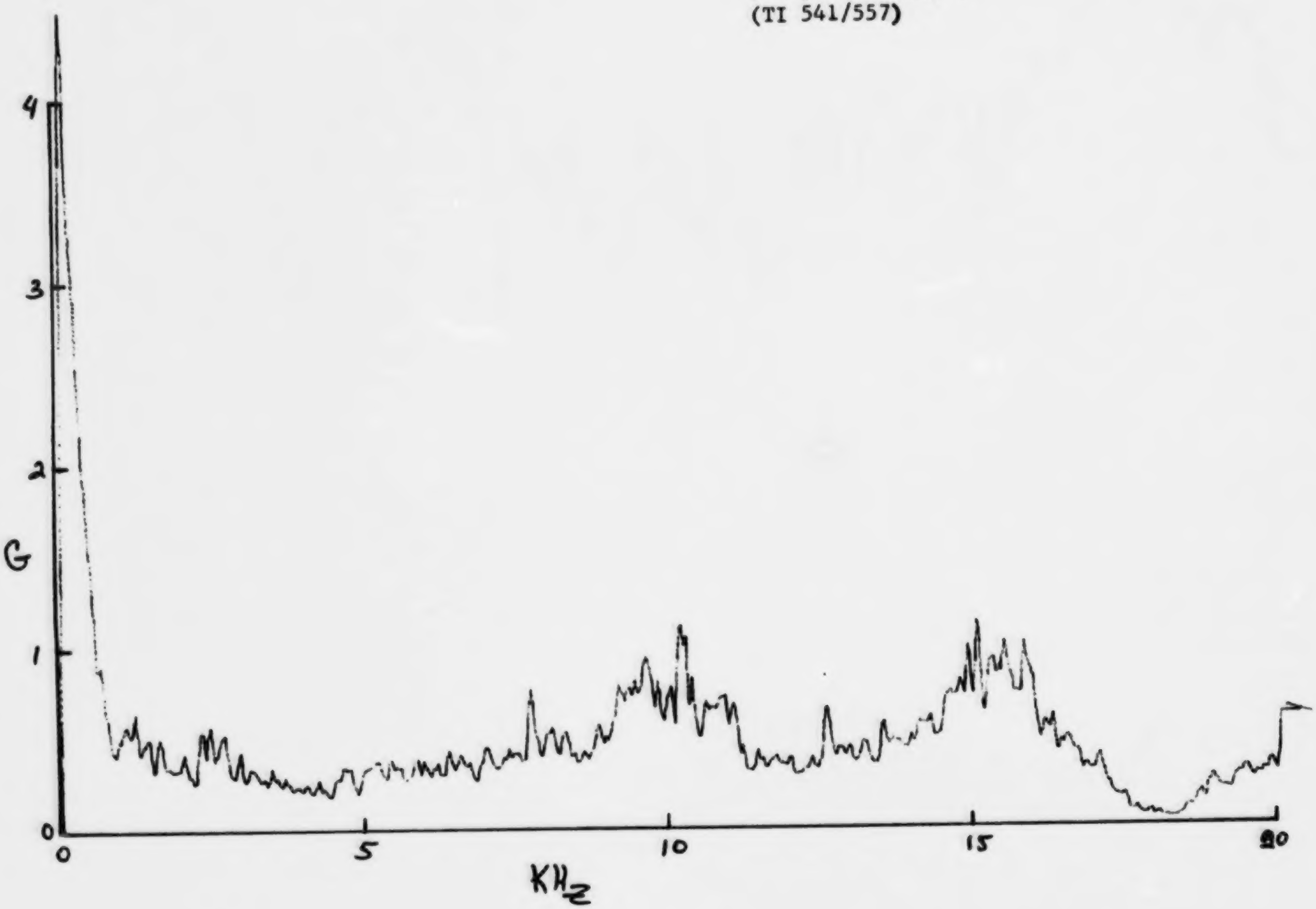
FV5-7

FV5 - 7   2.8 L, Ford V-6
Driver side rear head (axial)
C-85, 1600 RPM, T-
(TI 502/518)

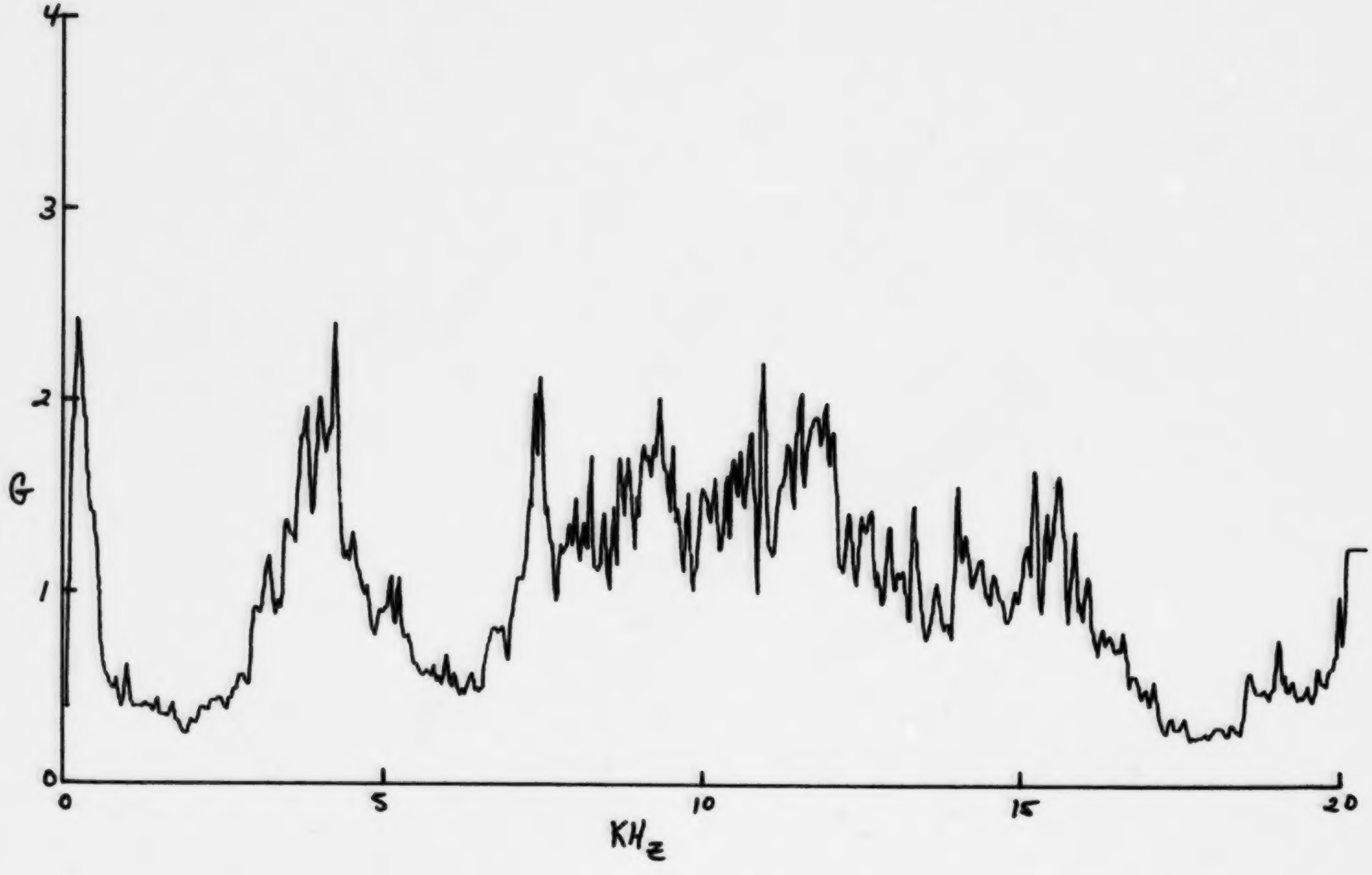


FV6 -5

FV6 - 5 2.8 L, Ford V-6
Head front bolt driver side(normal)
C-85, 1600 RPM, T-
(TI 541/557)

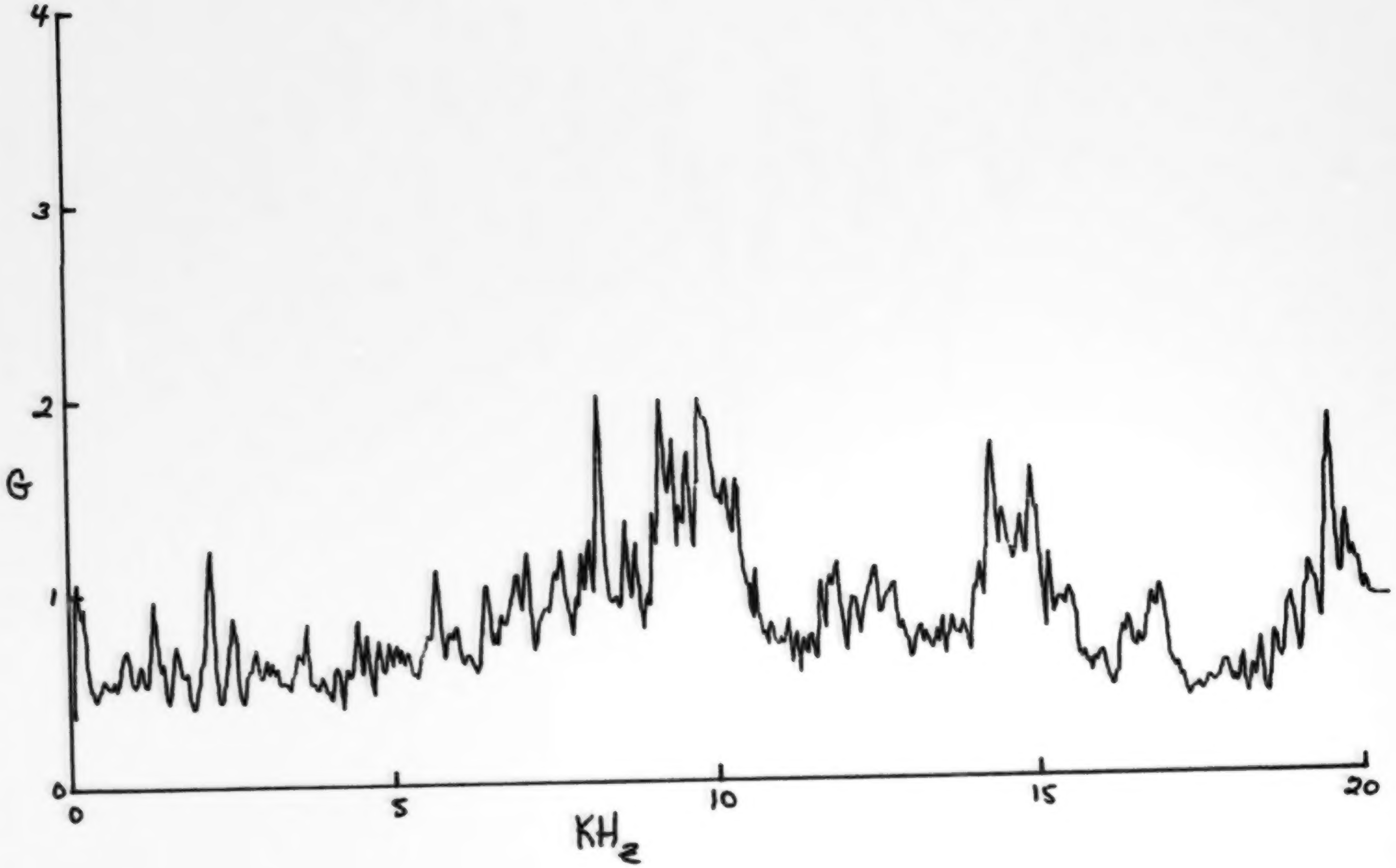


FV 6 - 6   2.8 L, Ford V-6
Passenger side rear head (axial)
C-85, 1600 RPM, T-
(TI 541/557)



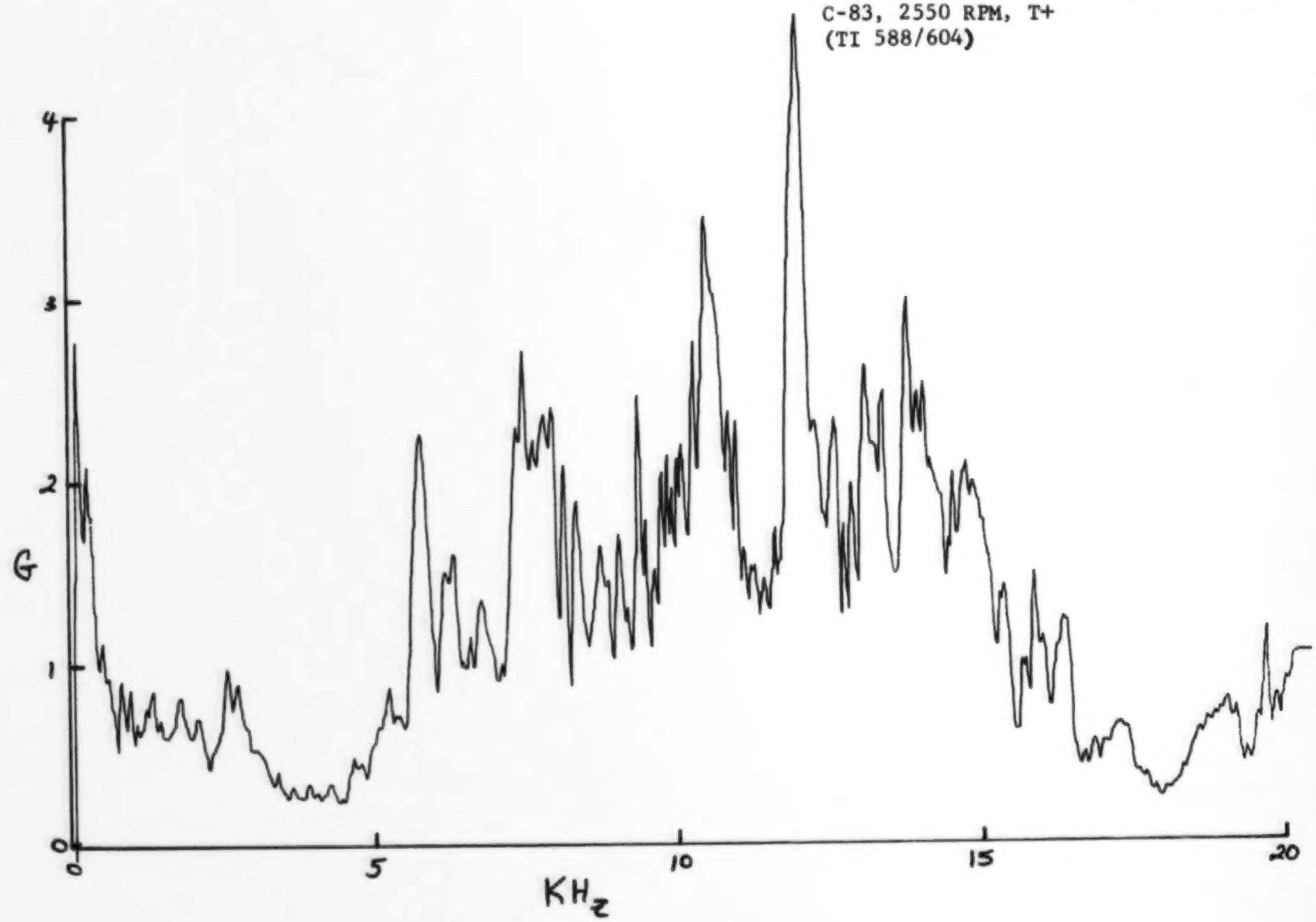
FV6-7

FV6 - 7   2.8 L, Ford V-6
Head front bolt passenger side(normal)
C-85, 1600 RPM, T-
(TI 541/557)



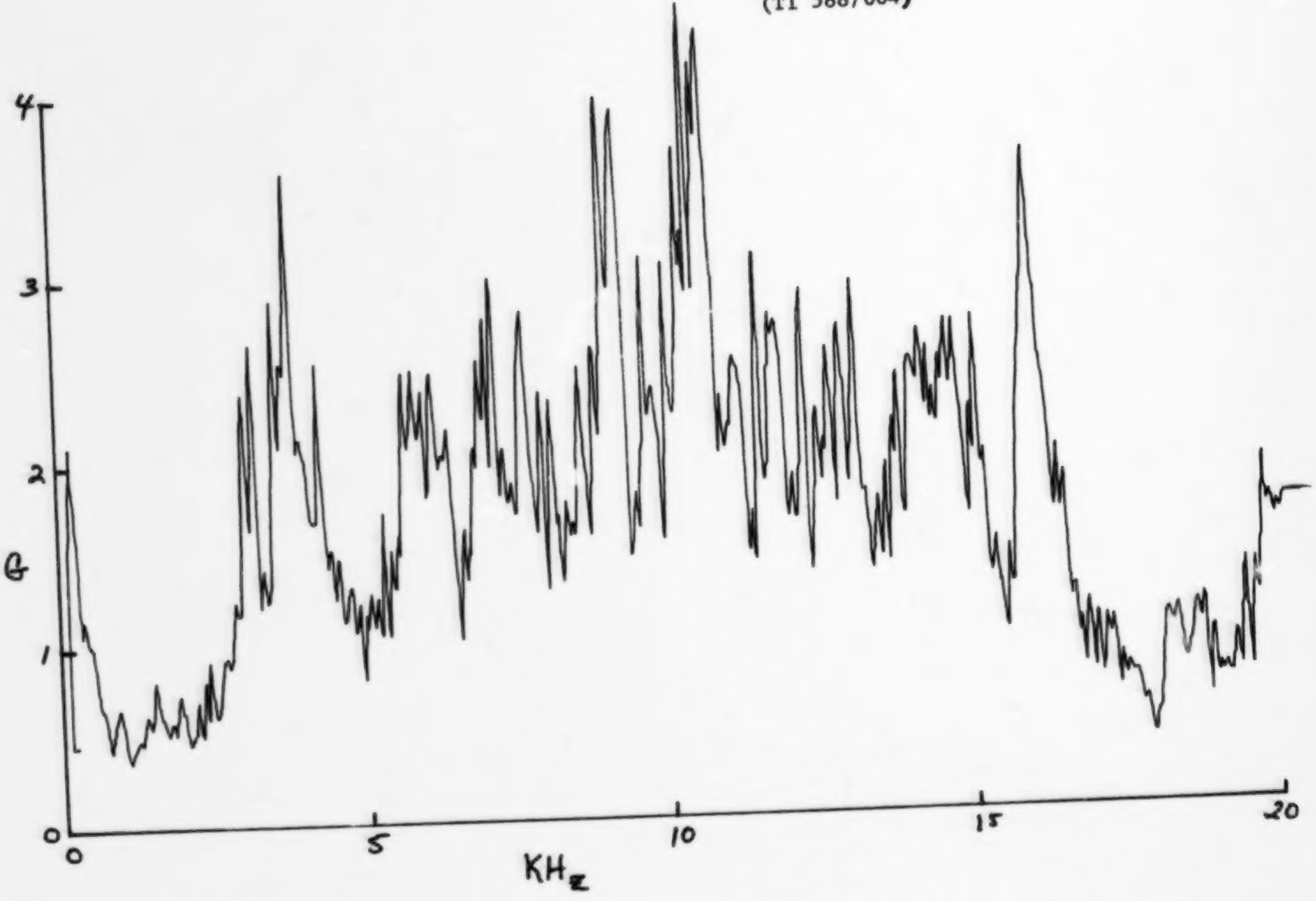
FV7-5

FV7 - 5 2.8 L, Ford V-6
Head front bolt driver side(normal)
C-83, 2550 RPM, T+
(TI 588/604)



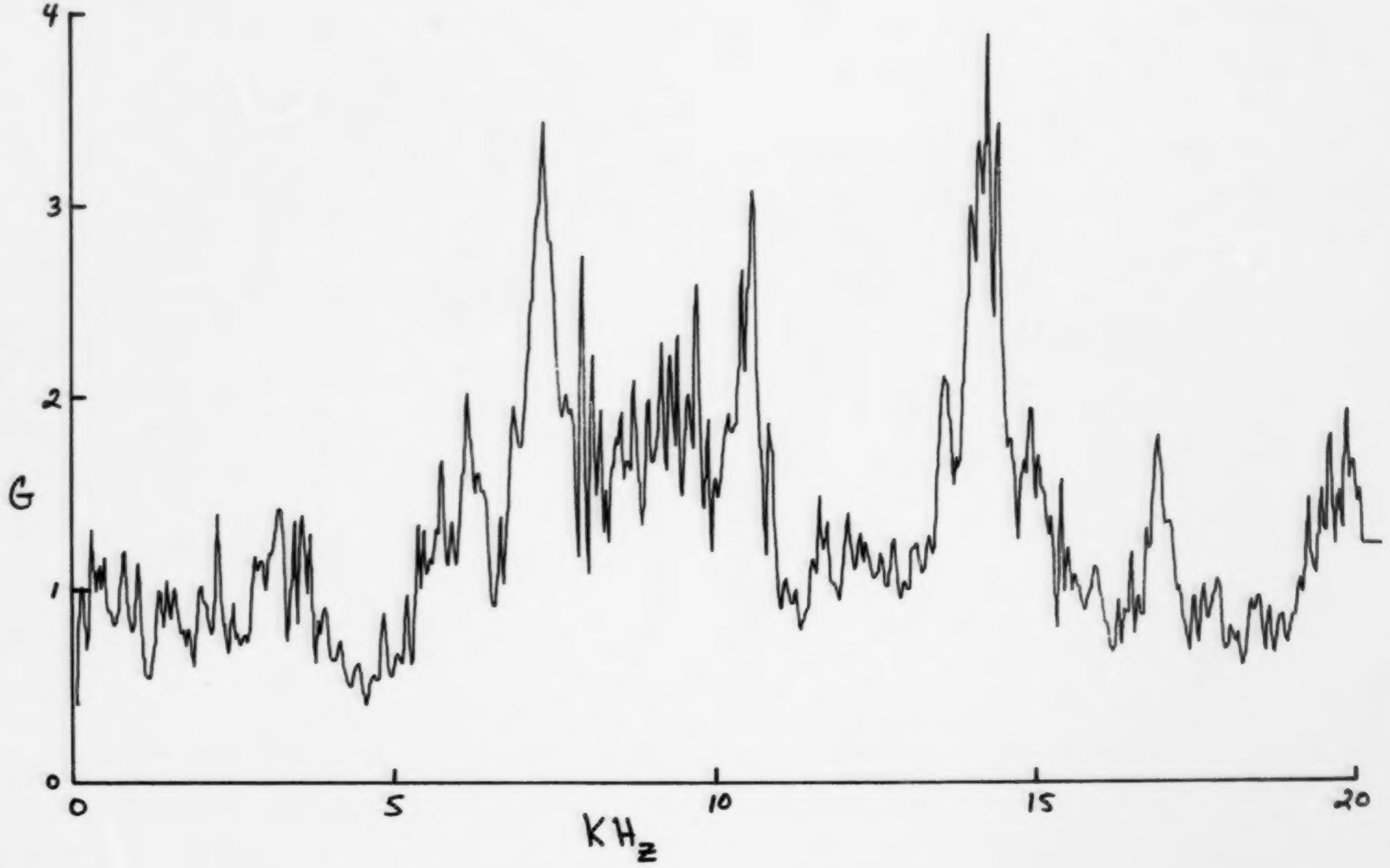
FV7-6

FV7 - 6   2.8 L, Ford V-6
Passenger side rear head (axial)
C-83, 2550 RPM, T+
(TI 588/604)

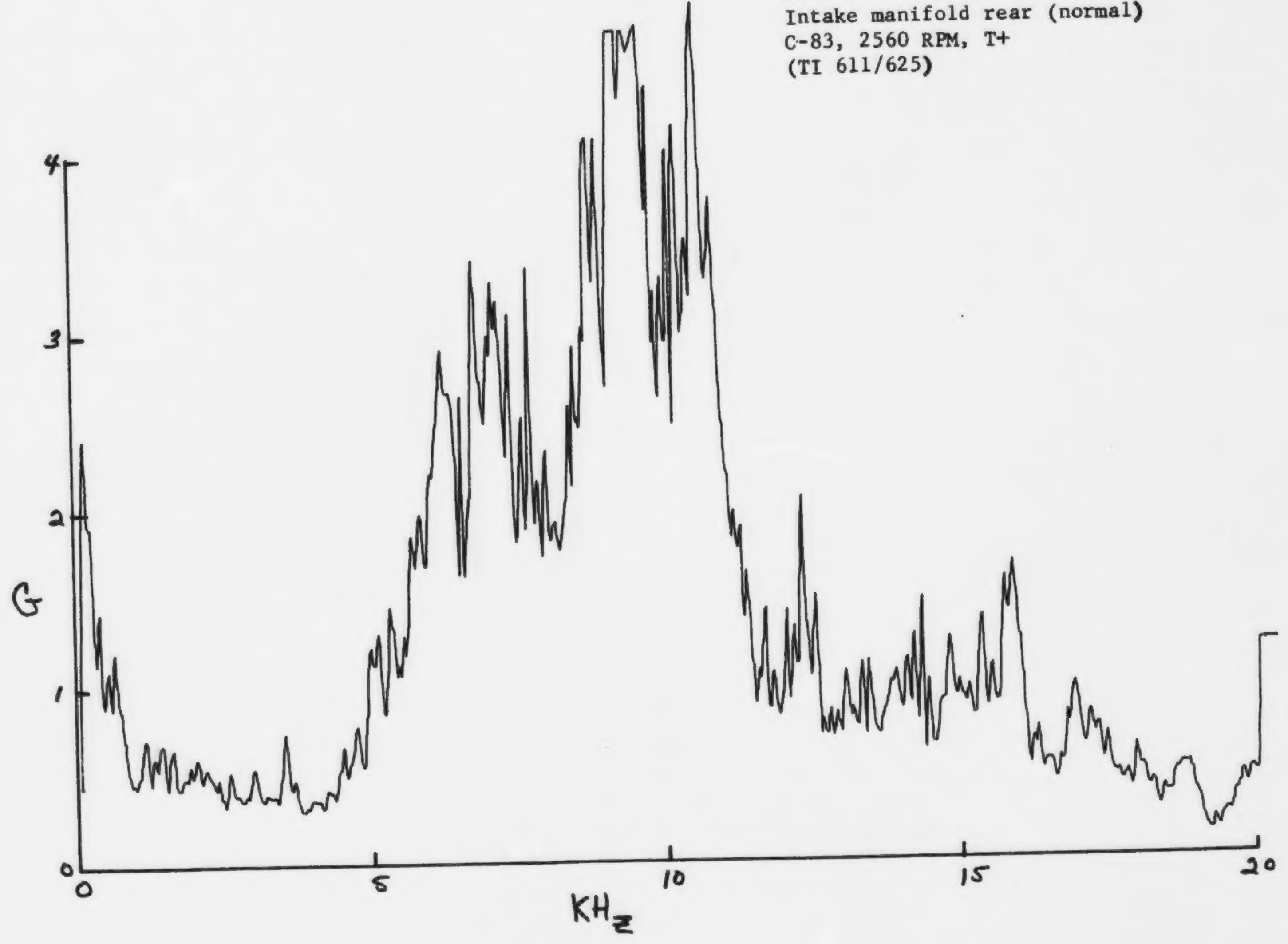


FV7-7

FV7 - 7   2.8 L, Ford V-6
Head front bolt passenger side (normal)
C-83, 2550 RPM, T+
(TI 588/604)

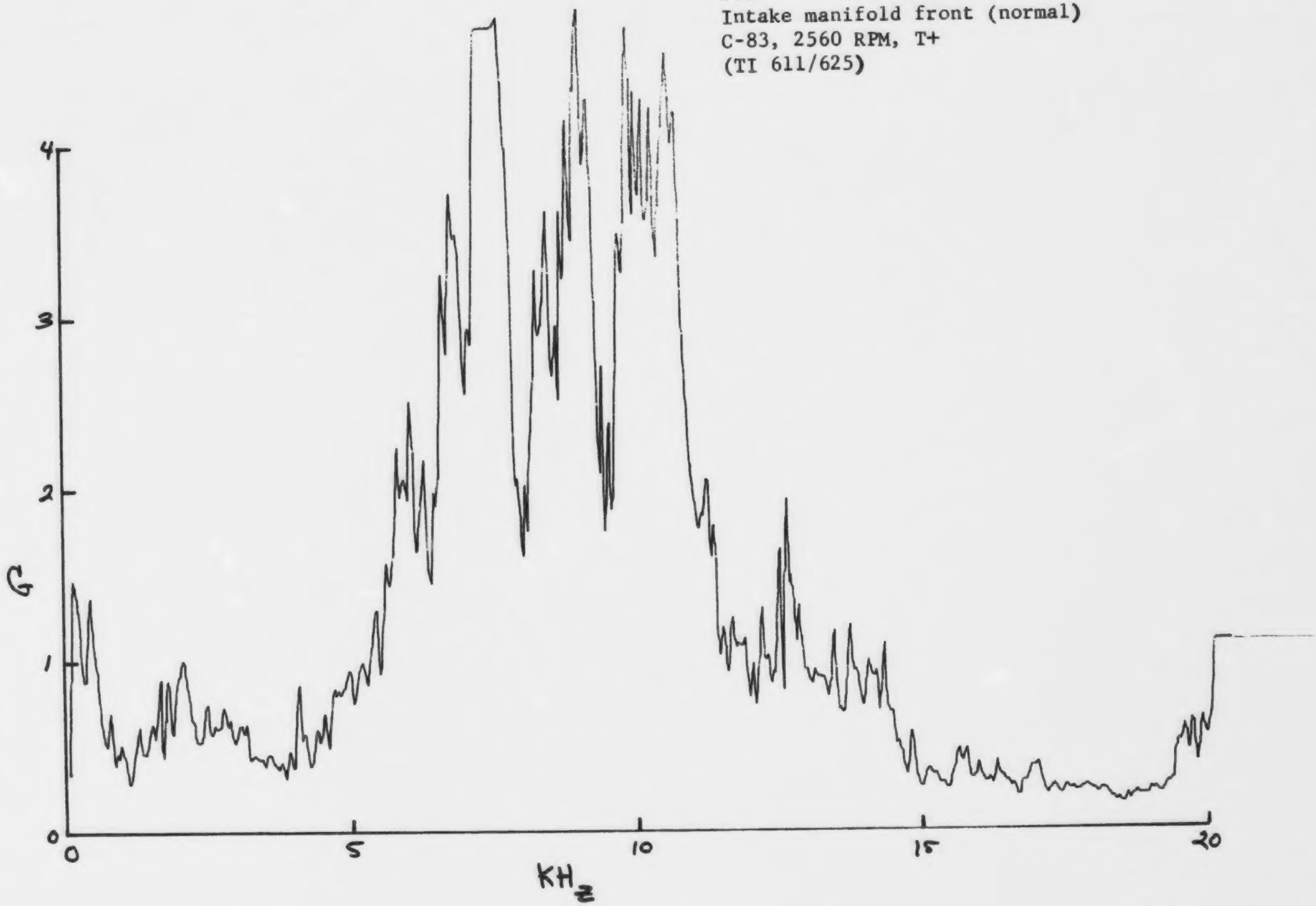


FV8-5

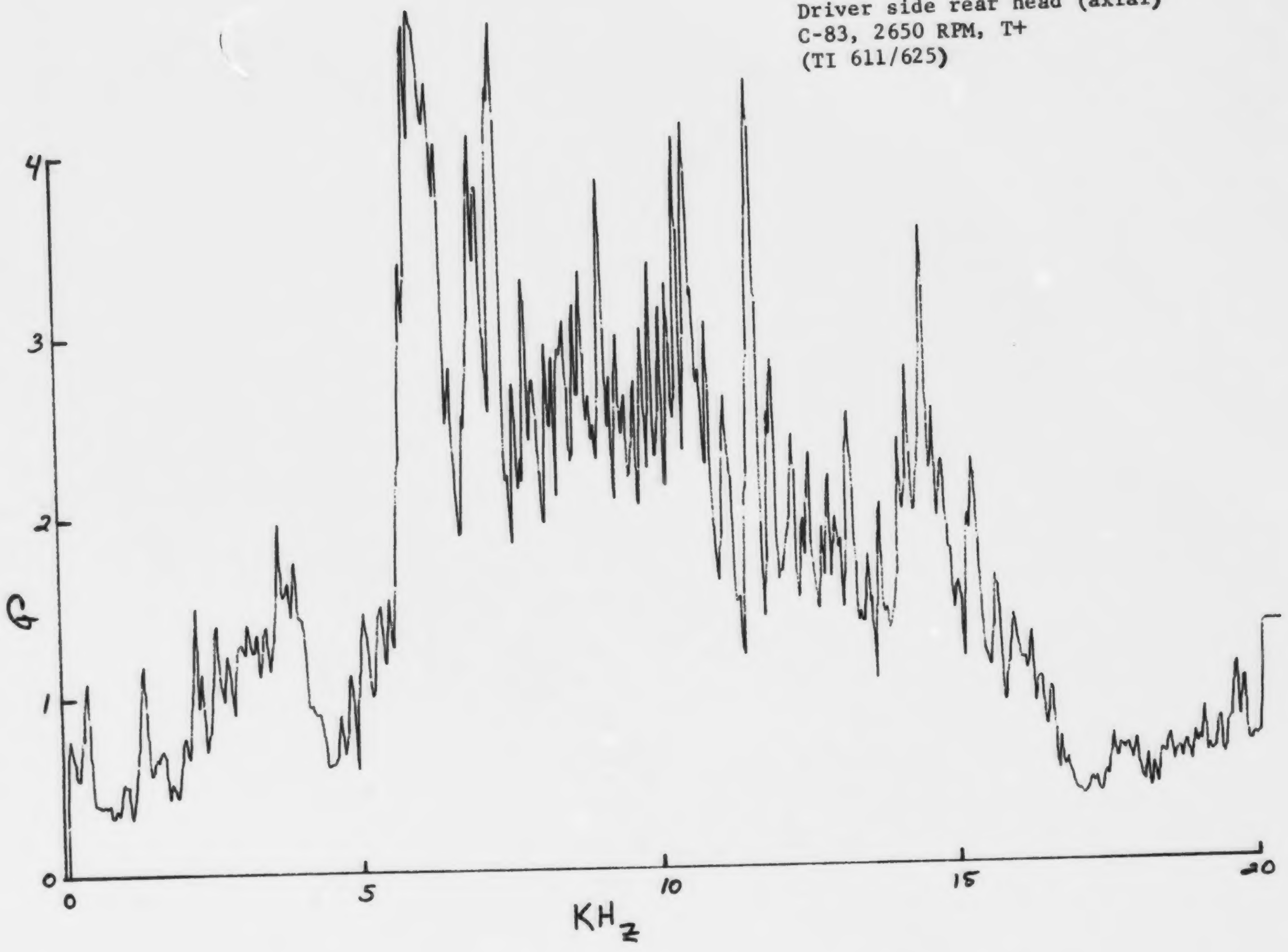

FV8 - 5   2.8 L, Ford V-6
Intake manifold rear (normal)
C-83, 2560 RPM, T+
(TI 611/625)

FV8-6

FV8 - 6   2.8 L, Ford V-6
Intake manifold front (normal)
C-83, 2560 RPM, T+
(TI 611/625)



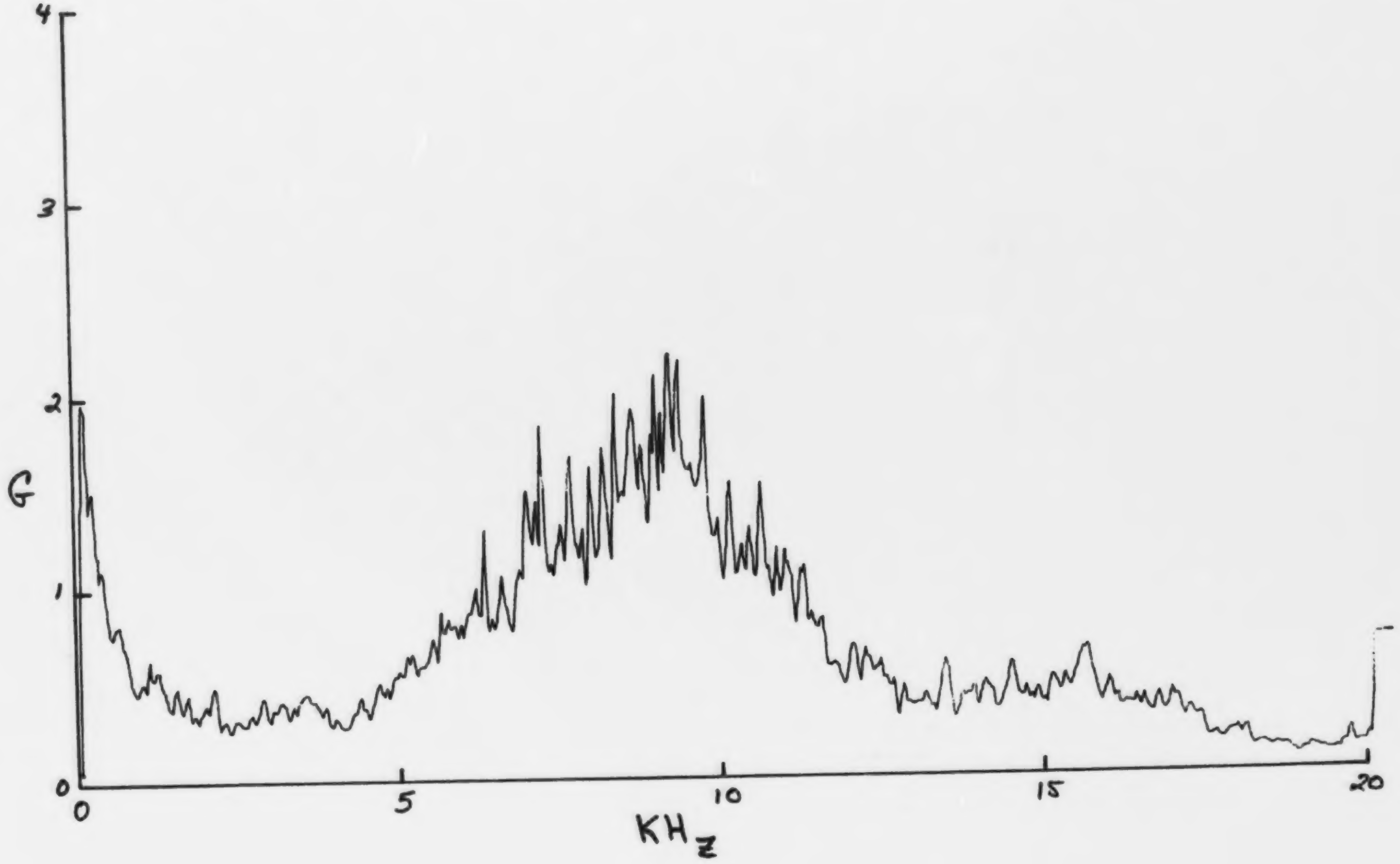
FV8-7



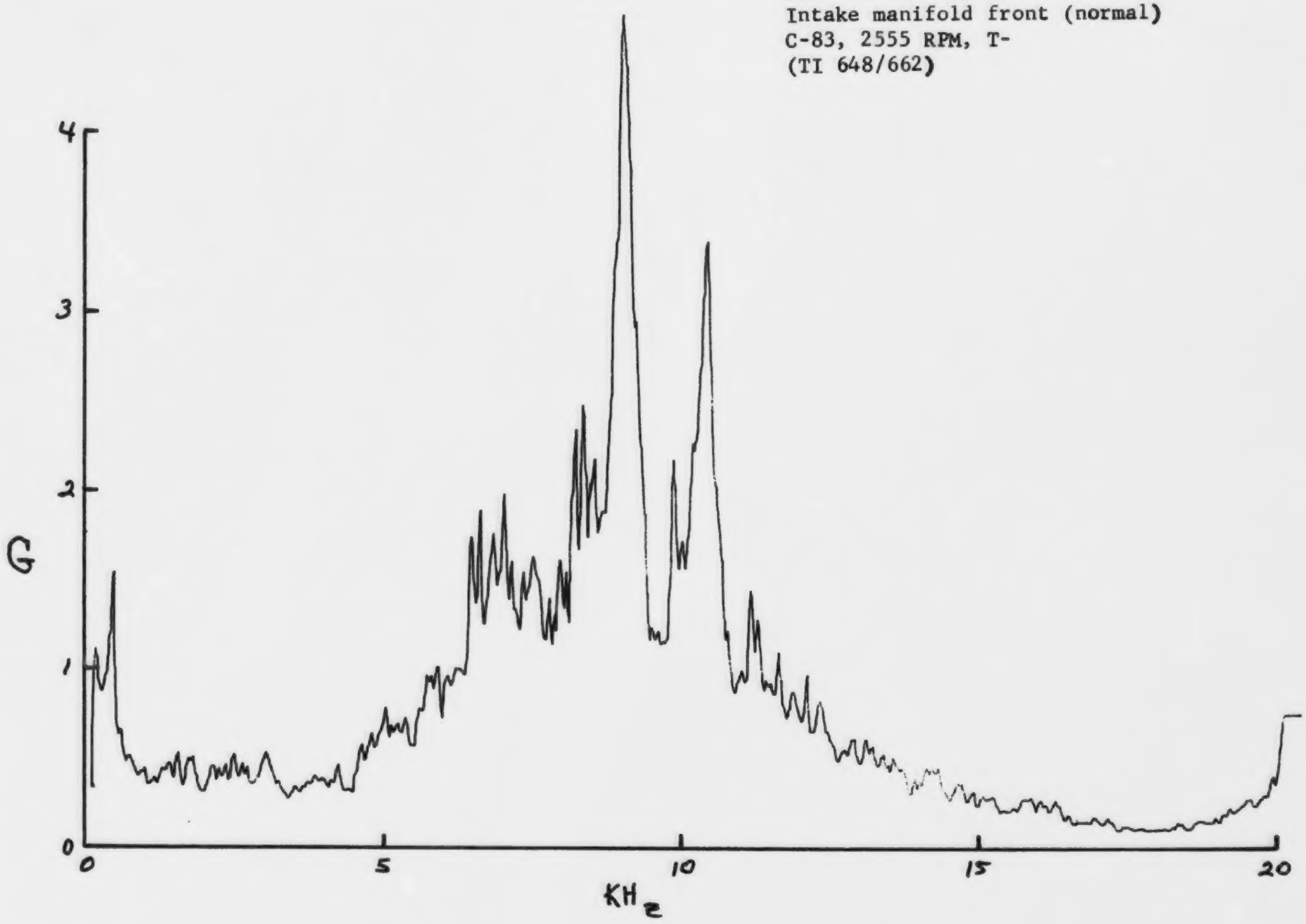
FV8 - 7   2.8 L, Ford V-6
Driver side rear head (axial)
C-83, 2650 RPM, T+
(TI 611/625)

FV9-5

FV9 - 5   2.8 L, Ford V-6
Intake manifold rear (normal)
C-83, 2555 RPM, T-
(TI 648/662)



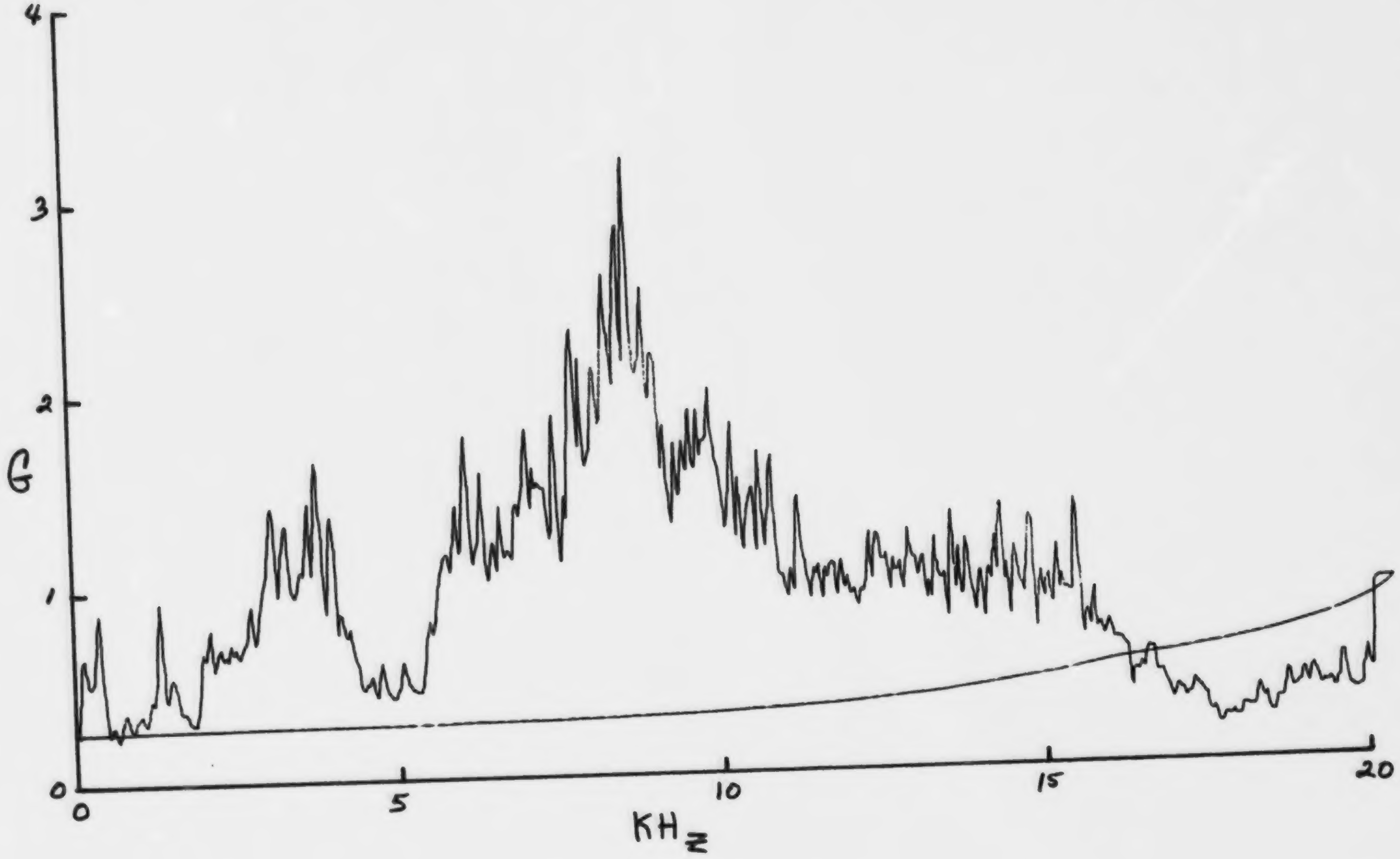
FV9-6



FV9 - 6 2.8 L, Ford V-6
Intake manifold front (normal)
C-83, 2555 RPM, T-
(TI 648/662)

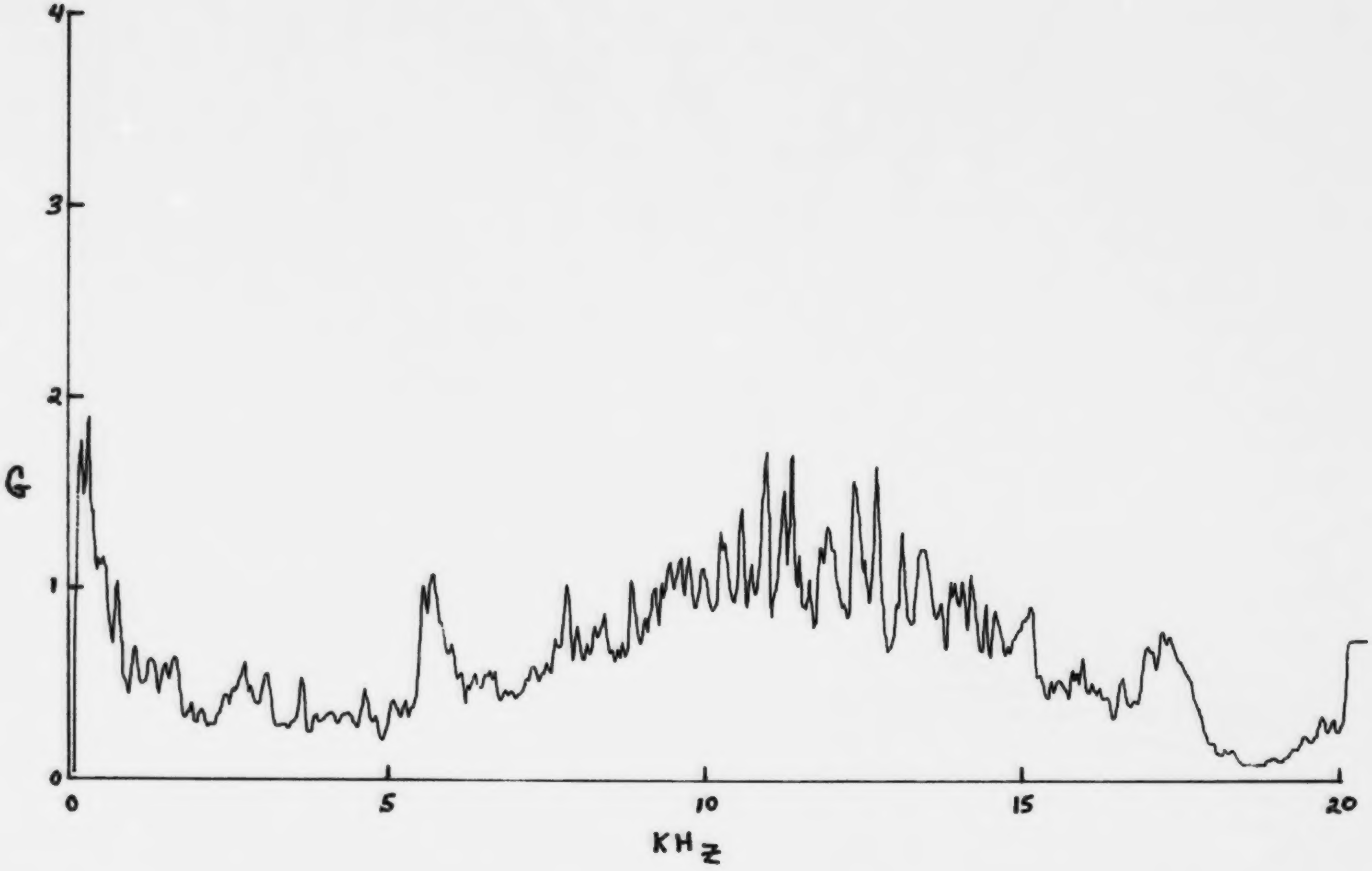
FV9-7

FV9 - 7   2.8 L, Ford V-6
Driver side rear head (axial)
C-83, 2555 RPM, T-
(TI 648/662)



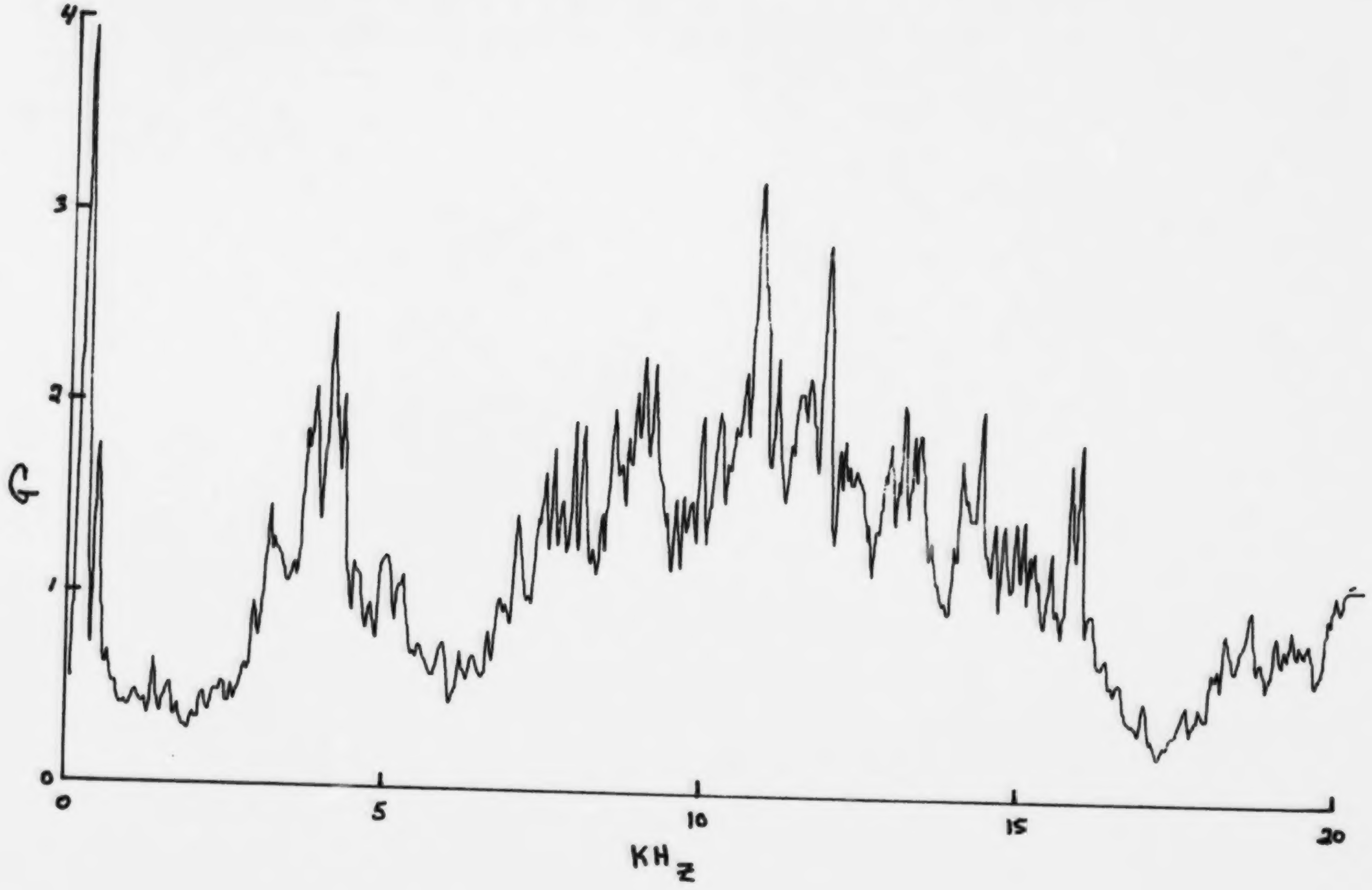
FV10-5

FV10 - 5   2.8 L, Ford V-6
Head front bolt driver side (normal)
C-83, 2555 RPM, T-
(TI 677/690)



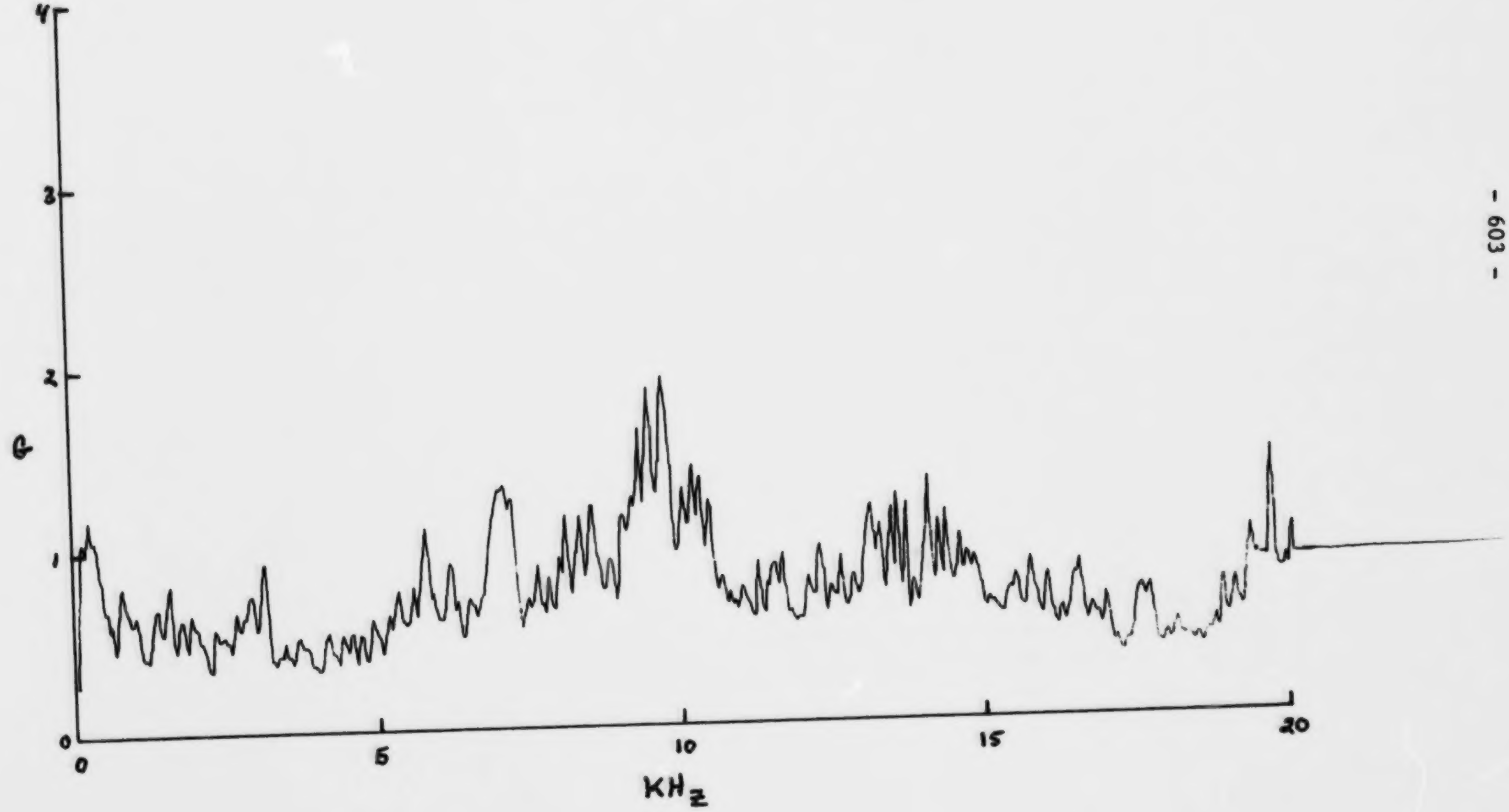
FV10-6

FV10 - 6   2.8 L, Ford V-6
Passenger side rear head (axial)
C-83, 2555 RPM, T-
(TI 677/690)



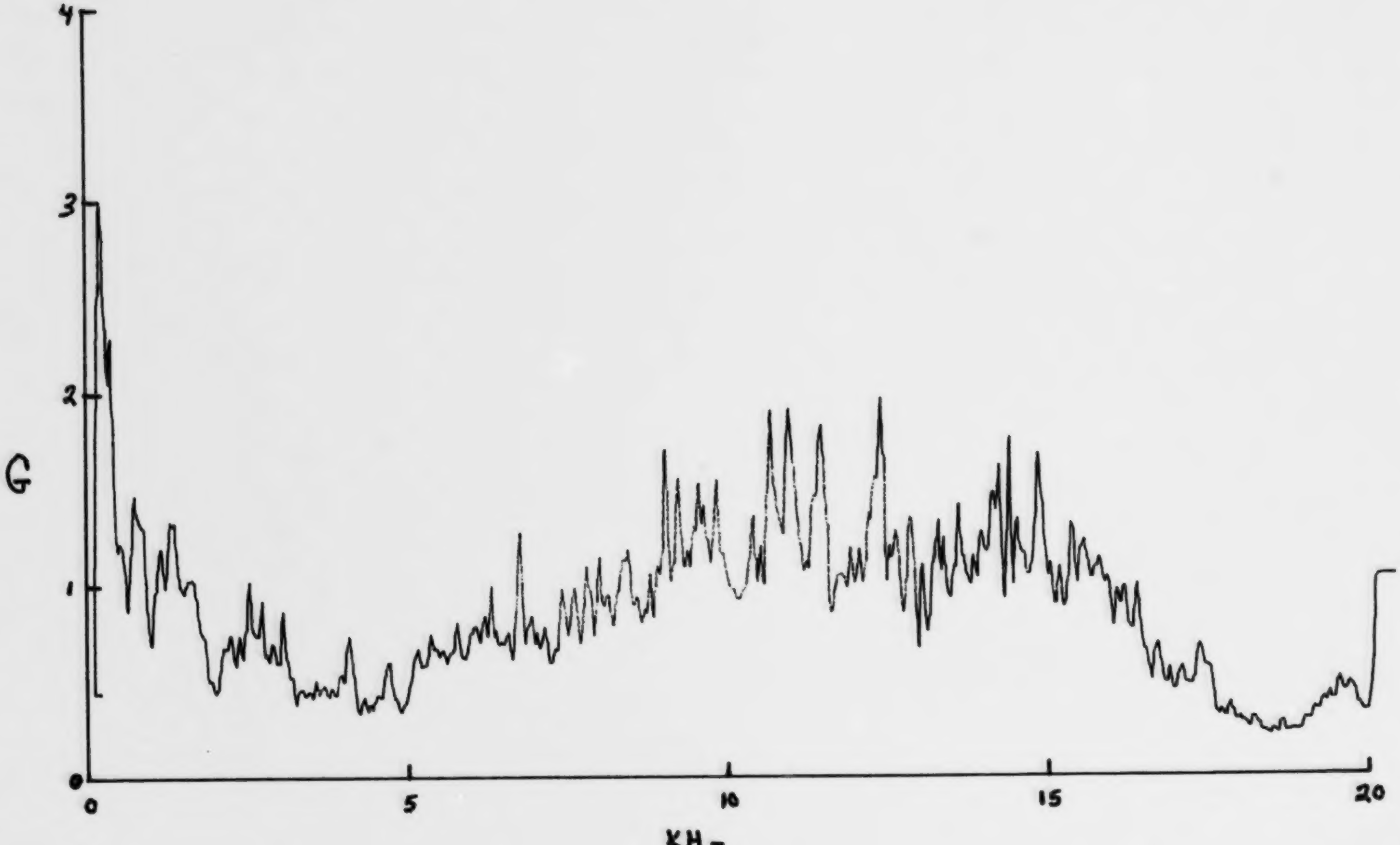
FV10 -7

FV10 - 7   2.8 L, Ford V-6
Head front bolt passenger side(normal)
C-83, 2555 RPM, T-
(TI 677/690)



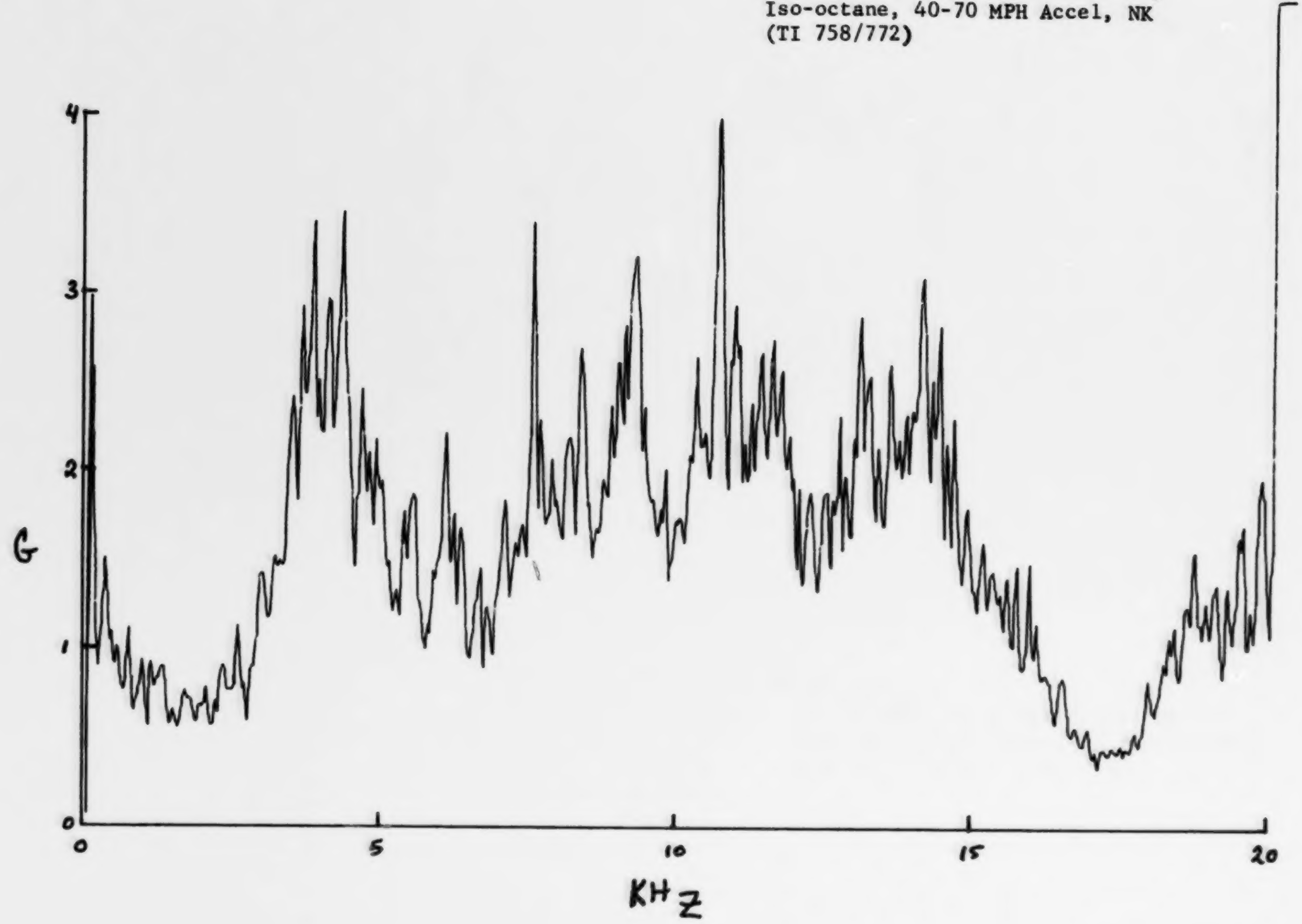
FV11-5

FV11 - 5   2.8 L, Ford V-6
Head front bolt driver side (normal)
Iso-octane, 40-70 MPH Accel., NK
(TI 758/772)



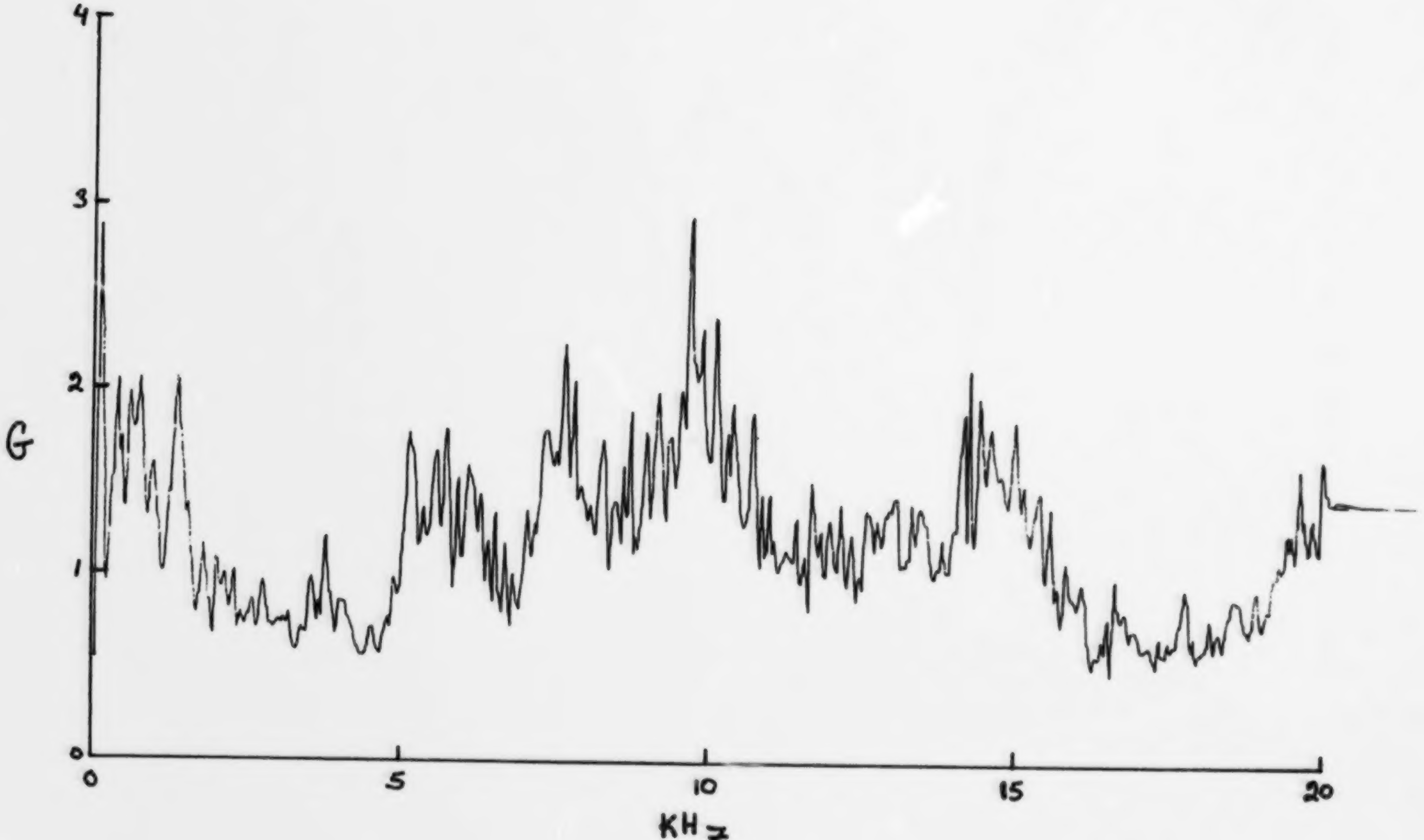
FV11-6

FV11 - 6   2.8 L, Ford V-6
Passenger side rear head (axial)
Iso-octane, 40-70 MPH Accel, NK
(TI 758/772)

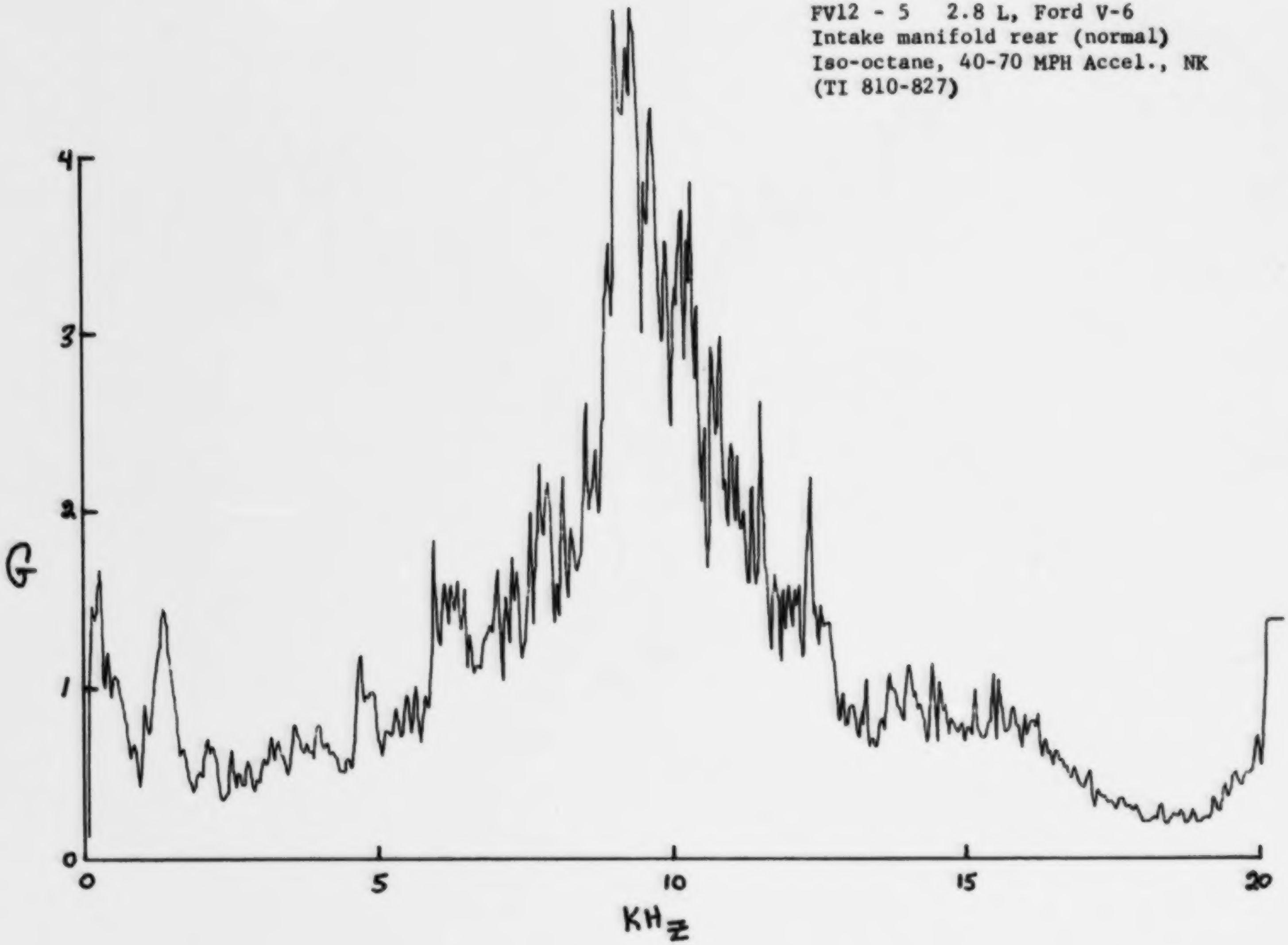


FVII-7

FV11 - 7   2.8 L, Ford V-6
Head front bolt passenger side(normal)
Iso-octane, 40-70 MPH Accel. NK
(TI 758/772)

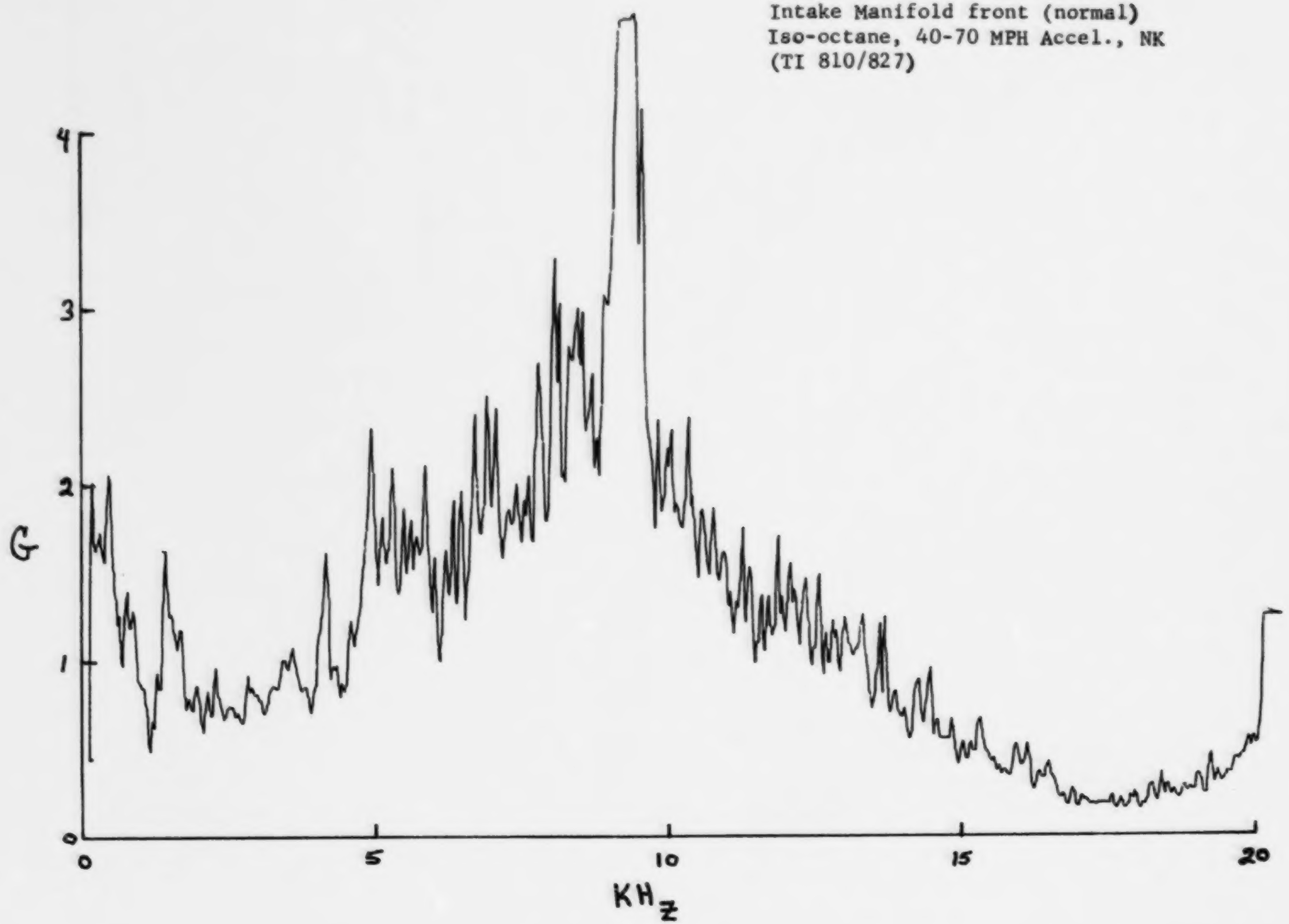


FV12-5



FV12 - 5   2.8 L, Ford V-6
Intake manifold rear (normal)
Iso-octane, 40-70 MPH Accel., NK
(TI 810-827)

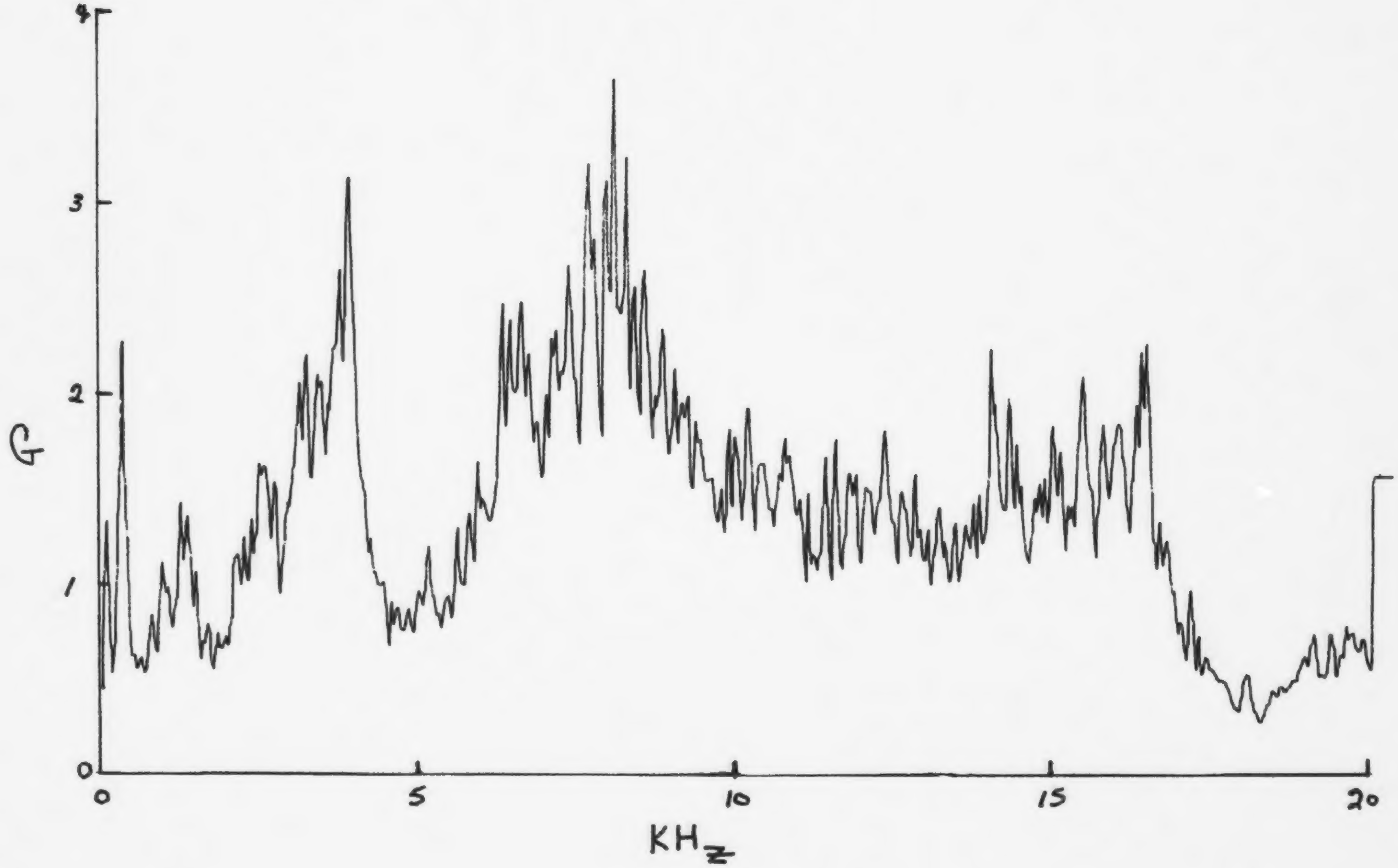
FV12- 6



FV12 - 6   2.8 L, Ford V-6
Intake Manifold front (normal)
Iso-octane, 40-70 MPH Accel., NK
(TI 810/827)

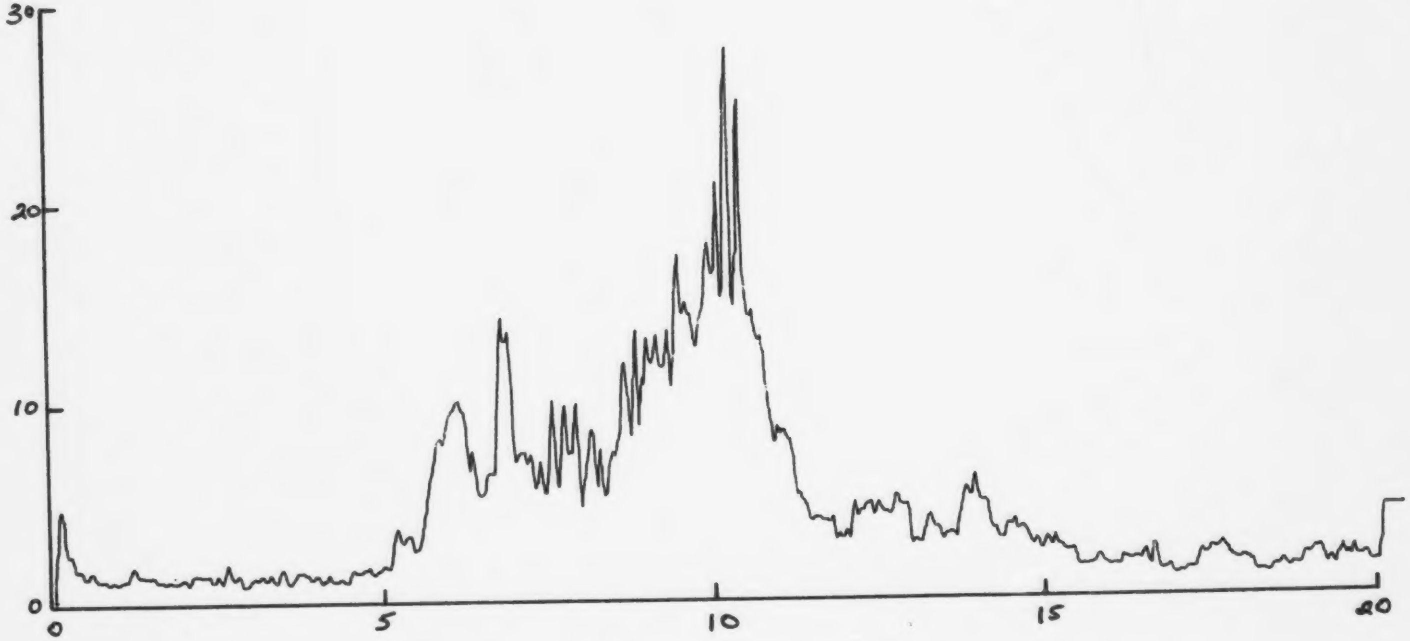
FV12 -7 2

FV12 - 7   2.8 L, Ford V-6
Driver side rear head (axial)
Iso-octane, 40-70 MPH Accel, NK
(TI 810/827)



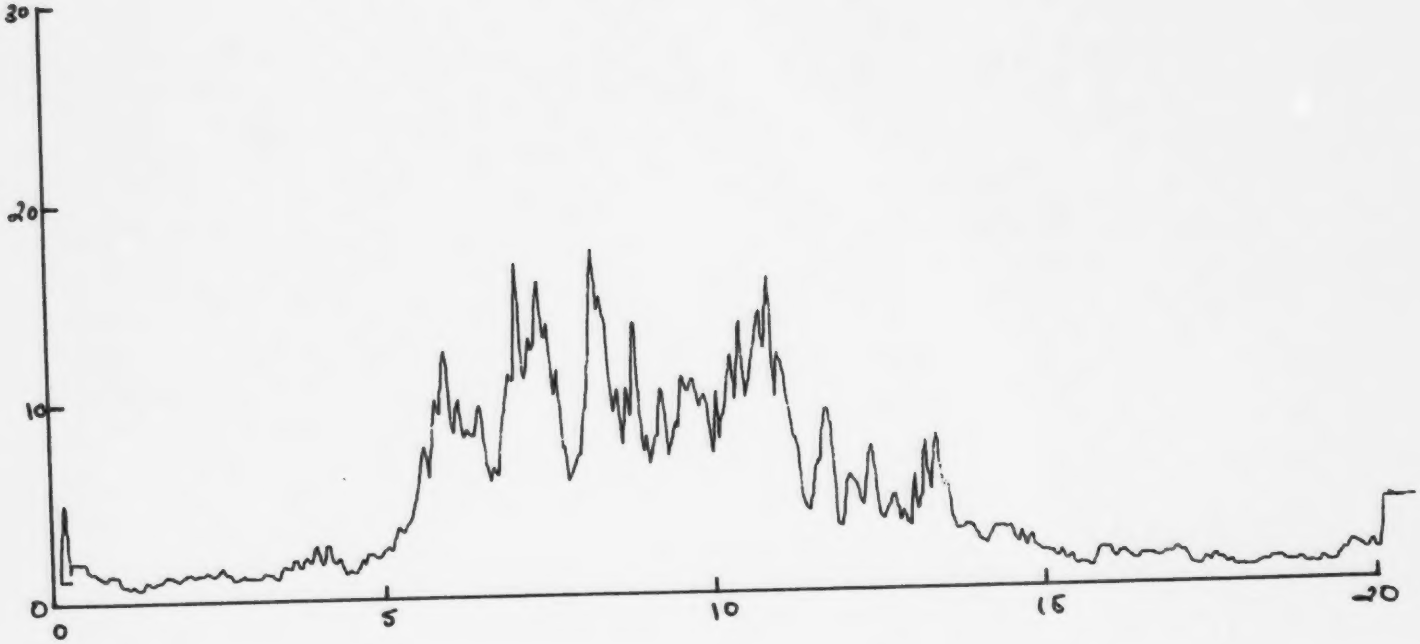
FV13-5
10V scale
(x10)

FV13 - 5   2.8 L, Ford V-6
Intake manifold rear (normal)
C-82, 40-70 MPH Accel., Too heavy
to rate, (TI 857/868)



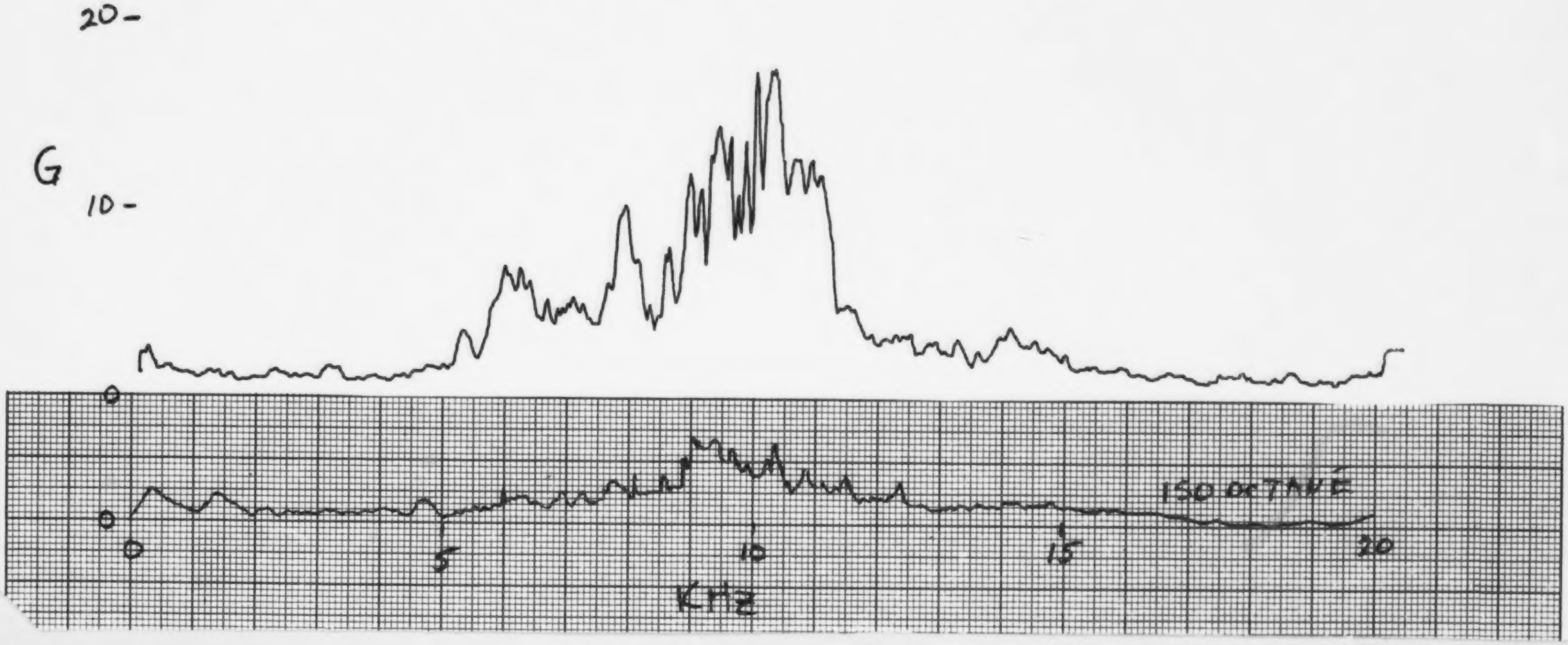
FV13-6
10volt
Rang.

FV13 - 6   2.8 L, Ford V-6
Intake manifold front (normal)
C-82, 40-70 MPH Accel., Too heavy
to rate, (TI 857/868)



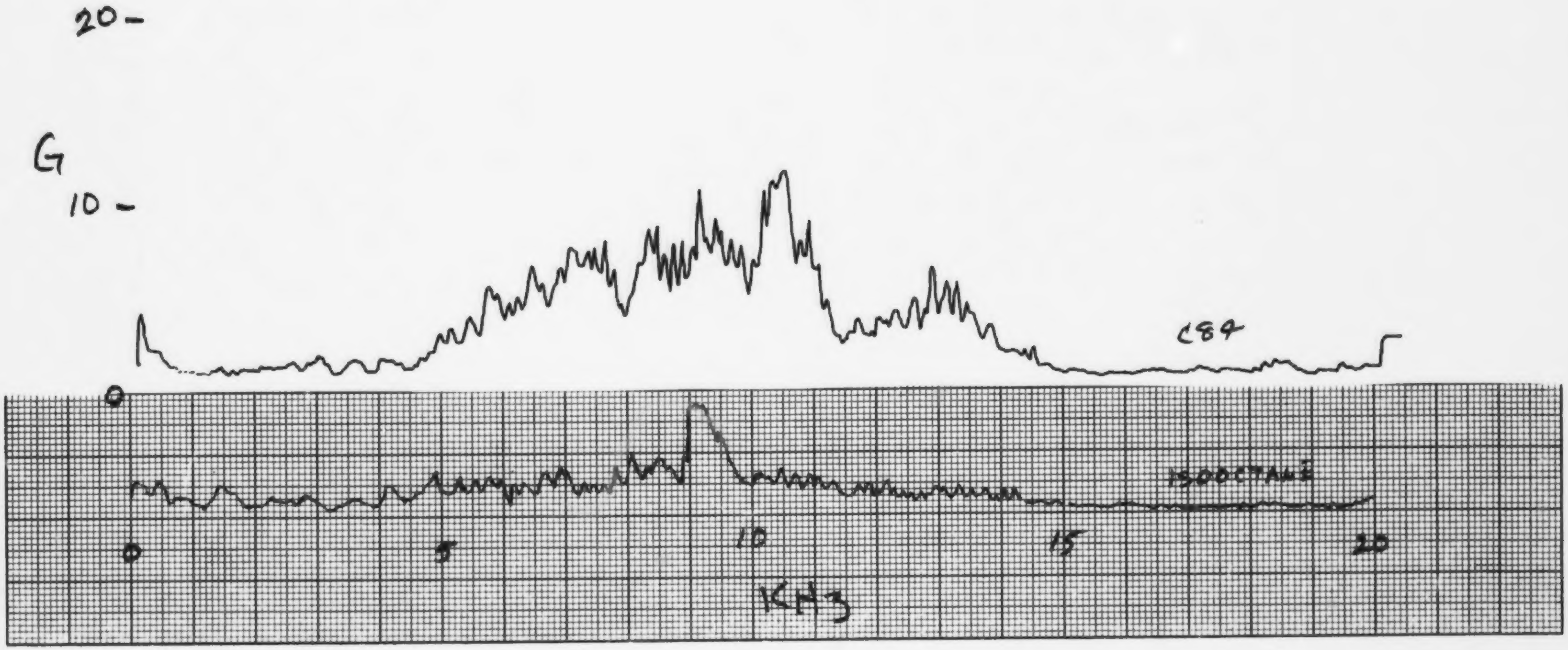
FV14-5.
10VOLT
Scale

FV14 - 5   2.8 L, Ford V-6   TOP
Intake manifold rear (normal)
C-84, 40-70 MPH Accel., VL+
(TI 889/904)



FV14-6
10VOLT
scale

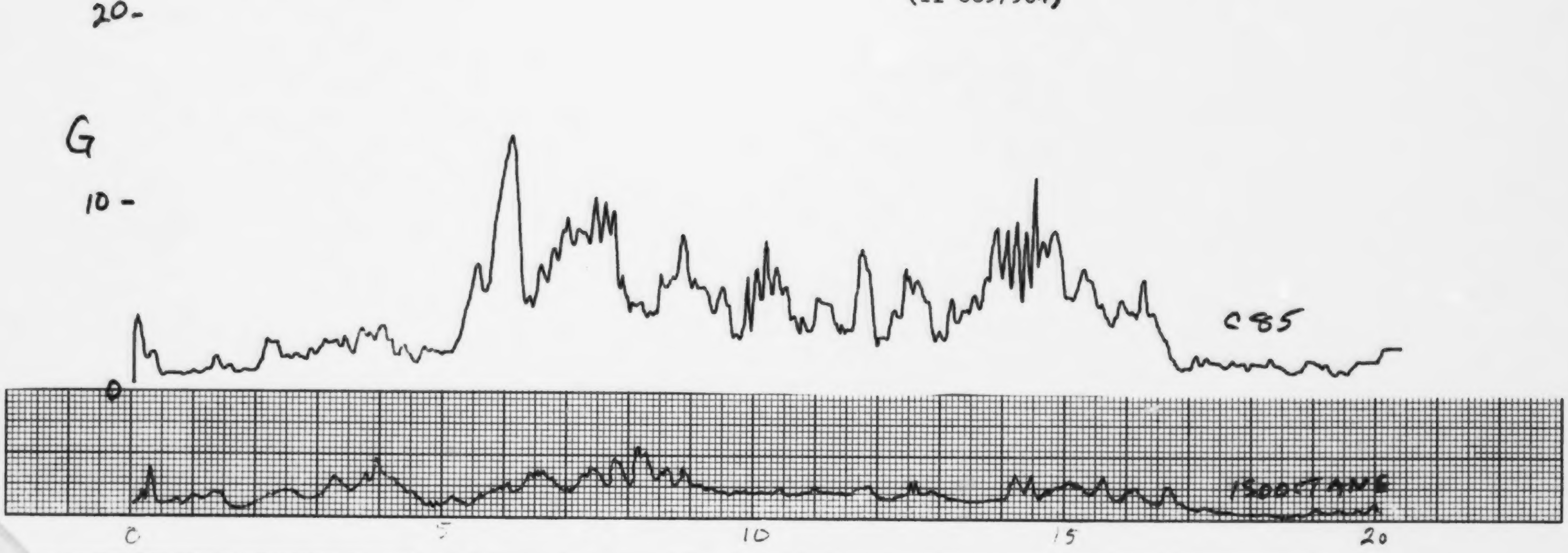
FV14 - 6 2.8 L, Ford V-6
Intake manifold front (normal)
C-84, 40-70 MPH Accel., VL+
(TI 889/904)



FV14-7
LOV Scale

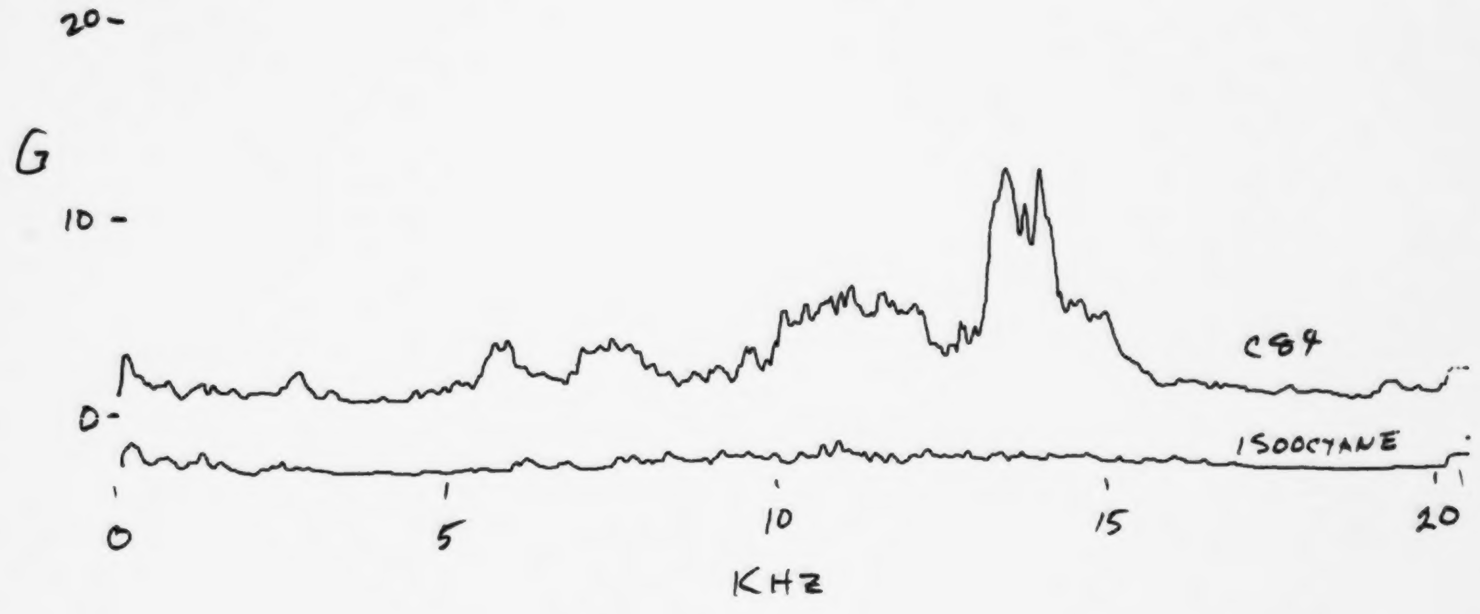
DRIVERS SIDE
REAR HEAD
AXIAL
40-70 MPH
TOP C85
BOTTOM ISOOCTANE

FV14 - 7   2.8 L, Ford V-6
Driver side rear head (axial)
C-84 40-70 MPH Accel., VL+
(TI 889/904)



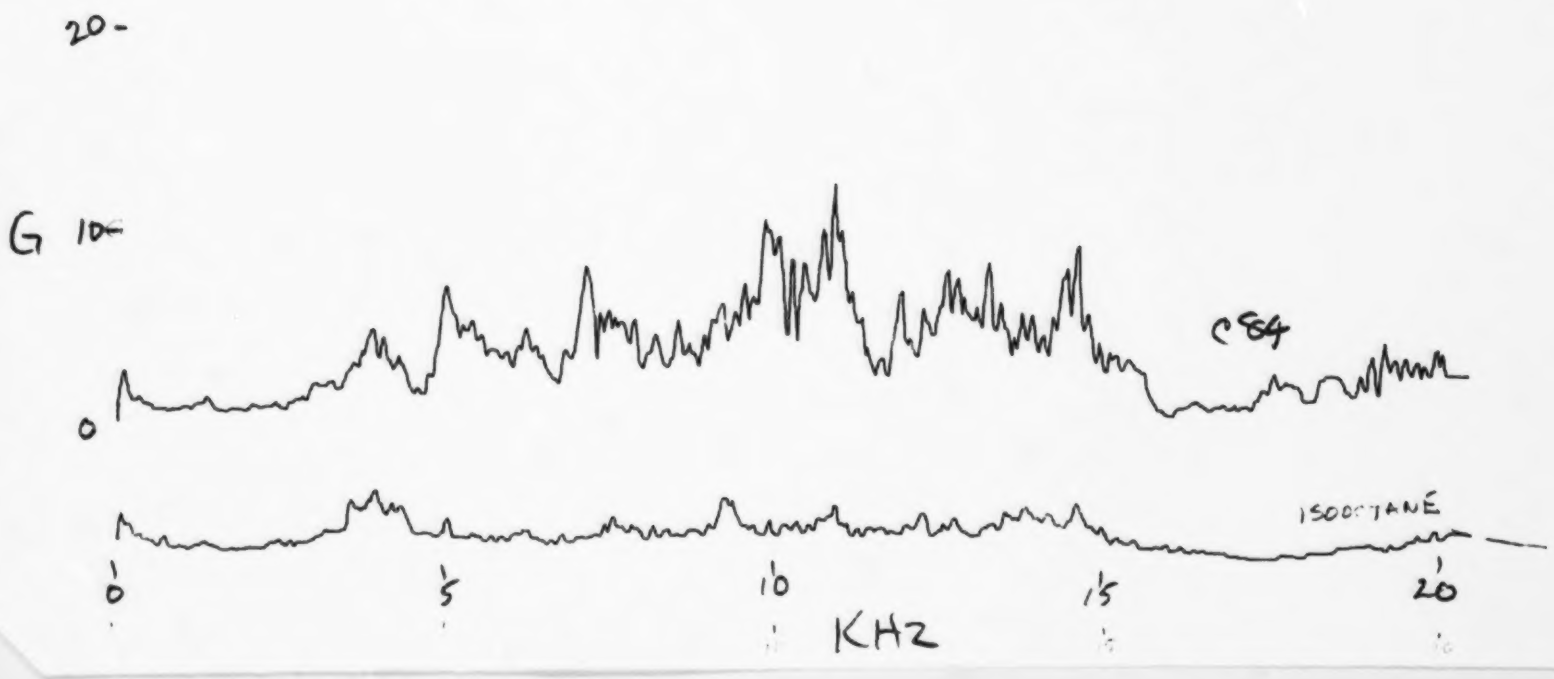
FV15-5
10V Scale

FV15 - 5   2.8 L, Ford V-6
Head front bolt driver side (normal)
C-84, 40-70 MPH Accel., VL+
(TI 926/942)



FV15-6
10V
scale

FV15 - 6   2.8 L, Ford V-6
Passenger side rear head (axial)
C-84 40-70 MPH Accel., VL+
(TI 926/942)



FV15-7
10V scale

FV15 - 7   2.8 L, Ford V-6
Head front bolt passenger side(normal)
C-84, 40-70 MPH Accel., VL+
(TI 926/942)